DRAFT REPORT

Candidate Variables for Monitoring Estuarine Nutrient Enrichment Within the NPS Coastal and Barrier Network

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Introduction

Nutrient enrichment of the coastal zone is a worldwide consequence of human population growth. Land clearing, fertilizer production and application, discharge of sewage and septic systems, and fossil fuel combustion have accelerated nitrogen and phosphorus loading to coastal ecosystems since the 1950's (Nixon 1995, Cloern 2001). Estuaries in the northeastern US are particularly threatened by human disturbances within the densely populated coastal zone (Roman et al. 2000). The Northeast (from Maine to Maryland) currently accounts for about one third of the coastal population of the entire United States (NOAA 1998). The population density of this narrow coastal fringe is more than double that of any other region of the country, and it continues to grow. The consequent residential, agricultural, and urban expansion will result in a continued increase in anthropogenic nutrient loading to the region's coastal zone. Estuaries can generally assimilate some degree of enrichment without major ecological ramifications, but excessive nutrient inputs typically lead to dense blooms of phytoplankton and fast-growing macroalgae, loss of seagrasses, and decreased oxygen availability in sediments and bottom waters (Valiela et al. 1992, Nixon 1995, Borum 1996, Bricker et al. 1999). Cascading effects may include changes in the species composition and abundance of invertebrates, decline in fish and wildlife habitat value, and the collapse of commercially harvestable fin- and shellfish stocks.

National Park units along the North Atlantic coast protect a total of about 1,891 square kilometers between Virginia and Maine. Approximately one quarter of this land area is submerged, including many coastal bays, estuaries, and lagoons (NPS 2000a). These areas serve as islands of relatively pristine coastal habitat within the northeastern urban corridor. Much of the watershed area of NPS coastal ecosystems, however, lies outside protective park boundaries and is thus subject to intense developmental pressures. Therefore, there is great potential for human disturbances to coastal watersheds to result in increased nutrient loading to park estuaries. Protecting the ecological integrity of park estuaries depends on implementing a scientifically-based monitoring program that is capable of detecting and predicting changes in ecosystem status (cf. NRC 2000). The ideal monitoring program will also identify causes and consequences of changes in estuarine condition so that remedial management actions can be developed as needed.

The NPS Vital Signs Monitoring Program was initiated to provide all national park units with scientifically sound information on the status and trends of their natural resources. Long-term ecological monitoring protocols are being developed for biogeographic networks of parks that share similar natural resource characteristics. The Northeast Coastal and Barrier Network consists of nine parks from Massachusetts to Virginia (Fig. 1). The four largest parks include extensive estuarine habitat (Assateague Island National Seashore, Maryland/Virginia; Cape Cod National Seashore, Massachusetts; Gateway National Recreation Area, New York/New Jersey; Fire Island National Seashore, New York). Colonial National Historic Park, Virginia, includes almost 8000 ha with a moderate amount of estuarine shoreline, and two small parks (Sagamore Hill National Historic Site, New York; George Washington Birthplace National Monument, Virginia) also include short stretches of estuarine shoreline. The last of the network parks, Thomas Stone National Historic Site, neither contains nor directly abuts any estuarine resources, and is not considered in this report. In addition, two parks within the adjacent Northeast Temperate Network also include extensive estuarine habitat (Acadia National Park, Maine; Boston Harbor Islands, Massachusetts). Descriptions of these North Atlantic park estuaries are contained in Appendix 1. These park units represent a wide range of sizes (33 ha to almost 20,00 ha), latitudes (37°11.3'N – 44°25.6'N or more that 800km of latitude), watershed geologies (shallow soils overlying granite bedrock vs. thick sandy glacial deposits), tidal range (micro-tidal to over 3m), and fresh water sources (surface water vs. ground water; Roman et al. 2000). Estuaries within these parks share fundamental characteristics, however, including temperate zone flora and fauna and the threat of nutrient enrichment as a primary management concern (Roman et al. 2000). These broad similarities are the basis for development of a uniform regional protocol for monitoring estuarine nutrient enrichment within the coastal park units of both the Northeastern Coastal and Barrier Network and the Northeastern Temperate Network.

Vital Signs Monitoring Protocols will be based on a core group of critical monitoring variables, or "vital signs", that collectively provide diagnostic information regarding the integrity of park ecosystems. Monitoring variables must be related to specific ecosystem functions, they must respond to stresses in an interpretable and a predictable manner that is outside the range of natural variability, and they should be anticipatory; i.e., they should predict impending changes in ecosystem structure or function, particularly those that could be averted through management actions (Dale and Beyeler 2001, Kurtz et al. 2001). Clearly, monitoring variables must be straightforward and relatively inexpensive to measure for program implementation to be feasible.

This report identifies a suite of variables for monitoring estuarine nutrient enrichment in the North Atlantic park units. An estuarine monitoring protocol currently under development at Cape Cod National Seashore through the NPS Prototype Monitoring Program is focused on detecting changes in nutrient inputs to Cape Cod estuaries and ecosystem responses to these changes (Roman and Barrett 1999). The Cape Cod prototype provided a springboard for extension to network-wide monitoring. The suite of variables selected for network application must collectively represent the key characteristics of park estuaries throughout the North Atlantic region.

Objectives of an Estuarine Nutrient Enrichment Monitoring Program

The ability to protect park estuaries from deleterious effects of nutrient inputs hinges on diagnosing local causes of nutrient enrichment, detecting changes in nutrient loads, and determining if nutrient inputs are near to exceeding thresholds that would result in shifts in ecosystem structure and function. The following monitoring questions are derived directly from these information needs:

1. Are nutrient loads to park estuaries increasing?
2. Are estuarine resources changing in response to nutrient inputs?
3. What are the sources of nutrient enrichment?

These objectives guided selection of variables for monitoring estuarine nutrient enrichment. The most important criterion in evaluating candidate monitoring variables was the potential for yielding data that would answer these questions.

Selection of Proposed Monitoring Variables

We selected monitoring variables for regional testing by assembling and synthesizing information from diverse sources, including technical workshops and meetings (Table 1), existing programs, and site visits to North Atlantic parks. A conceptual model linking human activities, nutrient loading, and estuarine ecosystem responses provided a framework for identifying monitoring variables (Fig. 2). This model was adopted during development of the Cape Cod prototype monitoring protocol as a result of workshop discussions among scientists and NPS natural resource management professionals (Roman and Barrett 1999). The model helps identify key ecosystem threats (agents of change) and responses to consider during the process of variable selection. Although this particular graphic was developed for Cape Cod, the relationships depicted in the conceptual model are applicable to issues of estuarine nutrient enrichment worldwide (e.g., see similar conceptual models in Sand-Jensen and Borum 1991, Dennison et al. 1993, Batiuk et al. 2000, Cloern 2001).

An exhaustive list of potential variables was established initially based on the ability to answer, at least in part, the monitoring questions above. An array of variables had already been evaluated at Cape Cod through extensive field testing to determine their suitability for long-term monitoring. Those variables emerging as robust candidates for local (i.e. Cape Cod) application were considered candidates for extension to regional monitoring of estuarine nutrient enrichment. Additional potential variables arose from consideration of estuarine characteristics at parks throughout the North Atlantic region and of existing monitoring programs with relevance to estuarine nutrient enrichment within the vicinity of network parks (Appendix 1). This analysis focused on identifying variables and data sources with potential utility for monitoring estuarine nutrient enrichment within North Atlantic Parks. Individual potential variables were then evaluated in terms of the established characteristics of effective monitoring variables (Table 2). The most effective monitoring programs include variables that span levels of ecological organization (organisms to landscapes), relationships (causes of and responses to stress) and complexity (structure, function, and composition; Dale and Beyeler 2001). Consequently, each variable was evaluated in terms of its relative contribution to a collective suite, with the goal of including representatives of different scales, trophic levels, and relationships to nutrient enrichment.

The analysis of existing monitoring programs (Appendix 1) revealed many sources of data relevant to nutrient enrichment of park estuaries. Despite these sources, however, data on many metrics are much less available than originally anticipated. The synthesis of information on types, quantity, and quality of existing data available for immediate use by the parks, or available to be leveraged with additional park effort, helped to identify potentially cost-effective variables for NPS Vital Signs monitoring. The efficiency associated with adopting uniform approaches for regional and national estuarine sampling across NPS programs and those of other federal agencies also guided variable selection. Potential variables were evaluated for consistency with two NPS programs also under development (national water quality monitoring in marine/estuarine waters, NPS in prep; and water quality inventory protocols for estuarine/marine systems, Berounsky in prep.), and with the long-standing Environmental Monitoring and Assessment Program / National Coastal Assessment of the US Environmental Protection Agency (Jackson et al. 2000, US EPA 2001a). Thus, the final list of candidate indicators for this protocol was influenced by both scientific and practical considerations.

The vital signs proposed for regional implementation are listed in Table 3a-c. These variables are well justified scientifically, and collection of data for the entire suite is deemed feasible from both practical and economic perspectives. Several additional parameters are described that require additional evaluation as potential vital signs. Existing scientific information suggests strong, predictive relationships between nutrient loading and these additional variables. However, further analysis of either their temporal or spatial variability is needed to establish their utility for regional monitoring.

Proposed Vital Signs

Agents of Change: Land Use, Point Sources, and Atmospheric Deposition

For a monitoring program to address questions regarding the causes of estuarine nutrient enrichment and trends in loading rates, monitoring variables must be related to the primary nutrient sources. Nutrients from land-derived sources are delivered to estuaries in surface and ground water flow. Quantifying actual loads of nitrogen and phosphorus requires spatially and temporally intensive measurement of stream and groundwater flux and nutrient concentrations (e.g. Doering et al. 1995, Nielsen 2002), and is beyond the scope of a regional monitoring program. However, the human activities contributing to increased nutrient delivery to coastal waters are well documented and are tractable at the landscape scale. The major land-derived sources of nutrient pollution are fertilizers and wastewater (Figure 2; Valiela et al. 1992, Nixon 1995). Nutrients from agricultural fields and domestic septic systems enter streams and groundwater through runoff and leaching, where they contribute to nonpoint sources of enrichment. Domestic wastewater is also delivered to estuaries as point-source sewage discharge. Increasing nutrient loads in streams and groundwater are consequently associated with high rates of urbanization and agricultural expansion (Valiela et al. 1992, Nixon 1995). Data on land use within the watersheds surrounding park estuaries are readily available throughout the North Atlantic region (Table 3a-c) as an indicator of nonpoint-source nutrient loads delivered in streams and groundwater, and the number of sewage and industrial effluent discharges permitted in the vicinity of park waters provides data on point-source inputs (Table 3a-c). Atmospheric deposition of nitrogen from fossil fuel combustion and fertilizer volatilization may also form a significant portion of the total nitrogen load to coastal waters (Figure 2; Nixon 1995), particularly in estuaries that are large relative to the size of their watersheds (NRC 2000). Monitoring data on atmospheric deposition of nitrogen either within or near 5 North Atlantic parks is available through the National Atmospheric Deposition Program, a nationwide network of precipitation monitoring stations operated cooperatively by the State Agricultural Experiment Stations, the U.S. Geological Survey, the U.S. Department of Agriculture, and numerous other governmental and private entities (Table 3a-c).

Ecosystem Responses

<u>Chlorophyll a</u>

Nutrient enrichment of coastal waters frequently stimulates phytoplankton production and results in increased phytoplankton biomass (Sand-Jensen and Borum 1991, Duarte 1995, Borum 1996). A strong linear relationship exists between input of dissolved inorganic nitrogen and phytoplankton production (when both are log transformed) in deep, phytoplankton-based marine systems (Nixon et al. 1996). Chlorophyll *a*, an indicator of phytoplankton biomass, shows a similar relationship in deep-water systems (Nixon 1992). Because of this, many national, regional, state, and local estuarine monitoring and assessment programs include measures of chlorophyll *a* concentration as an indicator of nutrient loading (e.g. Bricker 1999, Gibson et al. 2000, USEPA 2001b, and many programs summarized in Appendix 1). Several recent reviews of data from shallow coastal systems worldwide, however, have revealed considerable variation in the response of phytoplankton to nutrient enrichment (Borum 1996, Cloern 2001, Nixon et al. 2001), indicating that the linkage between nutrient increase and phytoplankton biomass is complex and system-dependent. It is now evident that many factors in addition to nutrient availability, including tidal energy, horizontal transport, optical properties, algal species composition, and benthic suspension feeders, exert strong control on phytoplankton population growth (Lucas et al. 1999, Cloern 2001, Nixon et al. 2001). These factors introduce non-linearity in the response of phytoplankton biomass to nutrient input, particularly in shallow, macrophyte-dominated estuaries.

Despite lack of a consistent linear response of phytoplankton to nutrient load, the fact that phytoplankton growth is indeed often nutrient-limited and the wide prevalence of chlorophyll *a* as a monitoring variable argues for the inclusion of chlorophyll *a* in a suite of estuarine vital signs. Although it is clear that low phytoplankton biomass does not necessarily indicate low rates of nutrient input, a trend of increasing biomass within a system may well correlate with increasing nutrient load. Long-term measurements of chlorophyll *a* in concert with other estuarine parameters may improve scientific understanding of the complex interactions among nutrient enrichment, inherent ecosystem attributes, and coastal ecosystem responses; this information should increase the sensitivity of the next generation of monitoring tools. Finally, since chlorophyll *a* data are widely available for estuaries nationwide (Bricker et al. 1999), this parameter offers a means to compare NPS coastal waters with many other systems.

Attenuation of Photosynthetically Available Radiation (PAR)

The importance of submerged aquatic vegetation (SAV, including seagrasses and freshwater submerged macrophytes found in upper reaches of estuaries) to the ecological function and habitat value of shallow coastal systems is widely recognized, and estuarine protection and restoration goals frequently emphasize the goal of maintaining or increasing SAV abundance (e.g. Chesapeake Bay Program 2000, many of the EPA National Estuary Programs profiled at http://www.epa.gov/owow/estuaries/list.htm). The principal environmental control on SAV productivity and distribution is light availability (e.g. Dennison and Alberte 1982, 1985; Dennison 1987, Duarte 1991), specifically the amount of photosynthetically available radiation (PAR, light between 400-700 nm) transmitted to plant leaves. A primary factor contributing to the attenuation of PAR through the water column is phytoplankton concentration (Figure 2; Dennison et al. 1993, Gallegos 1994, Krause-Jensen and Sand-Jensen 1998). Therefore, in systems showing increases in phytoplankton biomass with nutrient load, PAR attenuation is correlated with nutrient enrichment (Borum 1996). Measurement of average PAR attenuation thus provides information directly related to a living resource of management concern, and potentially related to nutrient enrichment. Attenuation of PAR also exerts control on phytoplankton growth, and is strongly influenced by concentrations of suspended inorganic material and colored dissolved organic matter (Gallegos 1994). Therefore, used in concert with chlorophyll *a* as a monitoring variable, information on PAR attenuation may offer insight into mechanisms causing changes in phytoplankton biomass.

SAV Distribution

The correlation between increased nutrient loading and declines in SAV distribution has been documented for estuaries worldwide (reviewed by Sand-Jensen and Borum 1991, Duarte 1995, Harlin 1995). Experimental studies have confirmed the causal relationships linking nutrient input, increased algal production, and decreased macrophyte growth and survival (Neckles et al. 1993, Short et al. 1995, Taylor et al. 1995, Sturgis and Murray 1997). The primary mechanism for loss of SAV in response to increased nutrient load is attenuation of light by fast-growing phytoplankton, epiphytic microalgae, and free-floating macroalgae, resulting in reduced availability of light at macrophyte leaf surfaces (Figure 2; Sand-Jensen 1977, Bulthuis and Woelkerling 1983, Twilley et al. 1985, Sand-Jensen and Borum 1991). The factors regulating which type of algae becomes dominant in response to nutrient enrichment are not well understood, however. In an analysis of the dominant primary producer present in 30 shallow coastal systems spanning a range of nitrogen input rates, Nixon et al. (2001) concluded that "there does not seem to be a regular or predictable sequence from seagrasses to macroalgae to phytoplankton or from seagrasses to phytoplankton to macroalgae." SAV growth integrates over these multiple sources of light reduction that occur with nutrient loading. In Waquoit Bay, Massachusetts, a significant negative relationship was found between eelgrass area and nitrogen loading (Short and Burdick 1996), and of the 30 systems they examined, Nixon et al. (2001) found a lack of SAV in those that were highly enriched. SAV-dominated estuaries are considered more sensitive to nutrient input than are estuaries dominated by plankton (NRC 2000), and restoration and protection of SAV habitat is often a primary management goal. Thus, the trend in SAV distribution over time offers an indicator of changes in nutrient load, while providing information directly applicable to critical habitat protection efforts.

SAV mapping programs provide information on trends in SAV distribution for many North Atlantic parks (Table 3a-c). If bathymetric surveys are available, SAV maps can also be useful in locating the maximum depth distribution of vegetation, which is directly related to light penetration through the water column (Dennison 1987, Duarte 1991). A decrease in the maximum depth limit of persistent SAV thus indicates long-term reductions in light availability that could potentially result from increased nutrient loading; indeed, a negative relationship between total nitrogen concentration and the lower eelgrass depth limit has been documented for Danish coastal waters (Borum 1996). Data must be interpreted with caution, however, because factors other than light availability at leaf surfaces also exert significant control on SAV distribution, including substrate type, wave energy, current velocity, and contaminant exposure (Koch 2001).

Sediment Organic Carbon

Water column and benthic processes are closely coupled in shallow coastal systems, so responses to nutrient enrichment may be observed in the sedimentary environment (Herbert 1999, Cloern 2001). Some of the organic production stimulated by nutrient inputs may be exported to nearshore waters, but this is generally a small fraction of the total primary production. For example, 10-15% of the primary production in Narragansett Bay is exported from the system (Nixon et al. 1995), and some systems with high rates of primary production export less organic matter than they produce (Smith and Hollibaugh 1993). Thus the majority of increased production that is stimulated through nutrient enrichment is metabolized or stored within the system. Much of this authochthonous organic matter sinks to the benthos and contributes to the pool of sediment organic material. Thus, organic carbon in the sediments may increase with nutrient load. Striking evidence is found in sediment cores from Chesapeake Bay, where a doubling of organic carbon content over the past 80 years corresponds to a period of dramatic increases in nutrient load (Cornwell et al. 1996).

Dissolved Oxygen

Organic matter on the estuarine sediment surface and within the sediments is mineralized by microbial decomposers, a process which consumes oxygen. Consequently, as the pool of sedimentary organic matter increases in response to nutrient enrichment, intense benthic microbial metabolism can result in reduced concentrations of dissolved oxygen in bottom waters and a decrease in the depth of the oxic-anoxic interface within the sediments (Day et al. 1989, Cloern 2001). Ultimately, the shift to anaerobic benthic metabolism will stimulate sulfate reduction and cause an accumulation of hydrogen sulfide in pore waters (Herbert 1999, Cloern 2001). The increases in extent and duration of bottom water anoxia and concentration of toxic sulfide compounds with nutrient enrichment have obvious negative implications for benthic fauna. Dissolved oxygen concentrations below 2.0-5.0 mg/l cause declines in the diversity and abundance of estuarine fauna (NRC 2000). Therefore, use of dissolved oxygen as a monitoring variable provides indirect information on nutrient loads and direct information on threats to estuarine consumers. It is important to note, however, that changes in both sediment organic carbon and dissolved oxygen concentrations may also occur without changes in nutrient inputs, but may rather signal deposition and decomposition of allochthonous organic matter.

Benthic Community Structure

Macrobenthic fauna have long been used for water quality assessments in estuarine and marine systems (Bilyard 1987, Holland 1990, Diaz 1992, Engle et al. 1994). Benthic infauna are relatively easy to monitor and they have limited mobility, so they cannot escape environmental stressors. Because invertebrate taxa exhibit different sensitivities to environmental degradation (Warwick 1988), information on faunal community composition yields insight into environmental conditions. For example, tubificid oligochaetes and capitellid polychaetes are considered tolerant of organic enrichment and low dissolved oxygen concentrations, so their relative proportion in the benthic community is indicative of pollution; in contrast, certain bivalve mollusks are considered sensitive to pollution (Engle et al. 1994). In some instances, the proportion of pollution-indicative taxa and pollution-sensitive taxa have been found to be more sensitive indicators of ecological impacts than were measures of water or sediment quality (Lerberg et al. 2000 and references therein). Many different benthic indices have been proposed that combine proportions of individual indicator organisms or distinct community attributes (e.g. number of species, diversity) into a single value. A simple description of the community composition and structure provides a level of diagnosis in and of itself, but also yields the data required for any subsequent benthic index calculation.

Required Ancillary Data – Temperature and Salinity

Two of the most important physical characteristics of seawater are temperature and salinity. Although temperature and salinity data are not directly applicable to questions regarding estuarine nutrient enrichment, these variables are critical to interpreting the responses of other parameters. Temperature is a primary determinant of the rate of biological processes. Thus productivity and growth of phytoplankton (Goldman and Carpenter 1974) and SAV (Marsh et al. 1986, Bulthuis 1987), microbial metabolism (Christian et al. 1989), sediment oxygen demand (Portnoy 1991), nutrient remineralization (Nowicki and Nixon 1985), and faunal recruitment (Day et al. 1989) are all strongly influenced by temperature, and the annual patterns of primary producers and consumers at temperate latitudes are largely a function of seasonal temperature differences (Day et al. 1989). Temperature also controls rates of chemical reactions and solubility of gases in estuarine water, and so affects dissolved oxygen concentrations. Estuarine organisms differ in their osmoregulatory abilities and salinity tolerances, so salinity similarly exerts strong control on the distribution and abundance of estuarine flora (Verhoeven and van Vierssen 1978, Adams et al. 1992) and fauna (Nordby and Zedler 1991, Montague and Ley 1993, Engle et al. 1994).

It is clear that temperature and salinity may influence the response of each proposed ecosystem monitoring variable to nutrient enrichment. Therefore, given the broad temporal and spatial variation in estuarine temperature and salinity, these physical characteristics must form part of any estuarine monitoring program. Temperature and salinity data may also provide insight into sources of nutrient input. For example, groundwater is typically colder than ambient estuarine water in the summertime, so that temperature contrasts can be used to locate groundwater discharge zones (Portnoy et al. 1998). Estuarine salinity is strongly dependent on river and stream flow, so that pulses of surface water are often recorded as decreases in salinity. A final justification for long-term monitoring of estuarine temperature and salinity is the potential for changes in these parameters to exacerbate effects of nutrient inputs in a changing global climate (cf. Short and Neckles 1999). For example, eelgrass becomes more susceptible to the negative impacts of algal epiphytes at high water temperatures (Neckles et al. 1993).

Parameters Requiring Further Evaluation

Winter Dissolved Nutrient Concentrations

Nutrient inputs to estuaries are subject to various biological, geochemical, and physical processes and transformations that control the ultimate spatial and temporal patterns of their concentrations in solution. Processes that contribute to nutrient retention in estuaries include sedimentation and burial, water-column and benthic nutrient regeneration, and assimilation by primary producers. In deep, phytoplankton-dominated systems, a linear relationship has been observed between the loading of dissolved inorganic nitrogen and the concentration in the water column (Nixon et al 2001), and many federal, state, and local estuarine and coastal monitoring programs are based on dissolved nutrients as indicators of nutrient enrichment status; Table 4 summarizes such programs in the vicinity of North Atlantic parks. Shallow systems where the photic zone extends to the sediments generally support a more complex autotrophic community, however, including seagrasses, macroalgae, and epiphytic and benthic microalgae in addition to phytoplankton. Nutrient uptake by this suite of primary producers is extremely rapid, so that there is often no relationship between nutrient inputs and the residual water column nutrient concentrations during the growth season (Fong et al. 1993, Tomasko et al. 1996, NRC 2000, Nixon et al. 2001). Although there are exceptions (e.g. Somes Sound at Acadia National Park), most of the estuaries within the North Atlantic park units are shallow systems for which standard, year-long water quality sampling of dissolved nutrients would appear to offer little insight into nutrient loads. Given the overriding control of plant uptake on nutrient concentrations, it is possible that dissolved nutrient concentrations during a winter index period, when primary producers are much less active, would better reflect nutrients inputs. The utility of winter dissolved nutrients as a monitoring variable would depend not only on whether nutrient concentrations were predictably related to loads, but also on whether the natural variability of nutrient concentrations is fairly low during this period. Several long-term water-quality data sets exist in the region for shallow, vegetated estuaries (e.g. Assateague Island National Seashore, Appendix 1; Narragansett Bay, Pilson 1985; York River tributary of Chesapeake Bay, described initially in Moore et al. 1996). Examination of these or similar data sets could reveal the utility of winter dissolved-nutrients as a monitoring variable for park estuaries.

Bacteriological Monitoring

Bacteriological monitoring, conducted routinely to test the safety of beaches for human contact recreation and to test estuarine shellfish for safe human consumption, provides the most widely available data within estuarine ecosystems across all coastal parks. Total coliform, fecal coliform, and *Enterococcus* species are used as indicators of fecal contamination in natural waters. The broad availability of bacteriological monitoring data suggests careful evaluation of these bacterial levels as an estuarine vital sign. Sources of fecal microbial contaminants include domestic septic and sewer systems, agricultural livestock operations, and direct input from wildlife and/or bathers. As indicators of fecal waste, bacterial levels may represent a reasonable proxy for sewage effluent at parks where there are point source discharges, failing individual septic disposal systems, or municipal combined sewage overflows contributing to estuarine nutrient load. Because existing bacteriological monitoring programs are nearly ubiquitous at parks in the network, a bacteriological vital sign would come at almost no additional cost to NPS. To test the utility of bacterial levels as an indicator of nutrient inputs, existing bacteriological data would have to be examined against sewage discharge in one or more systems where both variables are well documented.

Macroalgae and SAV Parameters

For the Vital Signs Monitoring Program to protect park estuaries from long-term effects of nutrient enrichment, the monitoring variables must be capable of detecting early increases in nutrient loads. A growing body of research points to physiological parameters of estuarine macrophytes as particularly valuable indicators of nutrient enrichment. Seagrasses and macroalgae respond to environmental conditions over time scales of weeks to months, thereby integrating fluctuations in nutrient load over fairly long periods. Concentrations of nutrients in submersed macrophyte tissue generally reflect nutrient availability (Hemminga and Duarte 2000), and have been proposed as indicators of enrichment. For example, Fong et al. (1998) exposed the macroalga *Enteromorphya intestinalis* to different levels of nitrogen fertilizer and found tissue nitrogen concentrations to correlate well with nutrient supply. Lee et al. (2001) similarly measured nitrogen content of *Zostera marina* (eelgrass) leaves along a gradient of nutrient enrichment. Both leaf tissue nitrogen concentration and leaf mass per unit leaf area reflected nutrient exposure, so that their ratio provided an even greater capability to discern changes in nutrient inputs. Stable nitrogen isotope ratios of eelgrass and macroalgae have also been shown to reflect the proportion of wastewater loading from groundwater sources (McClelland et al. 1997). Isotopic signatures responded to relative to relatively low wastewater input rates, suggesting that monitoring of macrophyte stable isotopes could be used in some estuaries (where groundwater is the primary nutrient source) to identify nutrient enrichment before extensive ecosystem degradation occurs.

Various structural and dynamic seagrass properties have also been proposed as sensitive indicators of ecosystem condition. Seagrass shoot density reflects both mortality and recruitment processes and has been suggested as an indicator of environmental stresses (Neckles 1994, Durako 1994). Eelgrass density declines predictably with declining light availability (Short et al. 1995). Because the primary mechanism by which nutrient enrichment affects seagrasses is through increased algal shading (Figure 2), we would predict decreases in shoot density with increased nutrient load. Indeed, eelgrass density has been shown to decrease with experimental enrichment of shallow mesocosms (Nixon et al. 2001) and with abundance of macroalgae in field manipulations (Nelson and Lee 2001). Dynamic characteristics such as leaf-area productivity (Durako 1994) and leaf elongation rate (Nixon et al. 2001) also reflect ecosystem condition.

Rooted vascular plants and macroalgae are much longer lived and grow more slowly than phytoplankton and epiphytic algae. Consequently, they will serve as better, more practical, physiological integrators of estuarine nutrient conditions than algal forms. It is also expected that macrophyte physiological indicators will prove to be highly responsive to subtle changes in nutrient enrichment, and hence more anticipatory that some of the more acute ecosystem response indicators such as SAV loss or reduced dissolved oxygen. Additional work is needed, however, to develop these demonstrated physiological fertilization responses into operationally functional indicators.

Next Steps

In order to translate the vital signs identified here into an operational monitoring plan for network estuaries, appropriate sampling protocols must be developed. First, existing sources of data (Appendix 1) must be examined to determine their applicability to park needs. For certain variables, or at some locations, data collected through established programs may suffice for Vital Signs monitoring. More often, it will be necessary to supplement data gathered by other programs with additional sampling in time or space to extend inferences to park resources. For all variables requiring on-site data collection, probabilistic sampling designs incorporating some type of random site selection must be developed (Fancy 2000). Sampling methods for all variables are well established and are supported by extensive documentation (e.g. USEPA 2001a,b, Berounsky in prep.). For all variables, however, the sampling frequency must be determined. In some cases this will require decisions concerning the relative merits of continuous vs. discrete sampling. Ideally, developmental protocols for all on-site data collection will be tested for at least one field season before they are incorporated into a network-wide monitoring plan. The final network monitoring plan should include the overall statistical sampling design for the network as well as mechanisms for compiling existing relevant data from other sources.

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Table 1. Technical workshops and work group meetings guiding variable selection process.

Meeting	Date	Focus	Participants
Coastal and Barrier Network Scoping Workshop, Water Quality Workgroup	April 13-14, 2000	Identification of monitoring questions Identification and ranking of many potential monitoring variables	Hilary Neckles – USGS John Portnoy – CACO Charles Rafkind – COLO Scott Gurney – SAHI Kirk Havens – VIMS Norm Rubinstein – USEPA Mark Ringenary – GATE Gary Rosenlieb – NPS WRD Rijk Morawe – GEWA/THST Brian Sturgis – ASIS
Coastal and Barrier Network, Estuarine Nutrient Enrichment Workgroup	February 12, 2001	Designed approach for selection of monitoring variables	Hilary Neckles – USGS Charles Roman – USGS Scott Nixon – URI Norm Rubinstein – USEPA Jim Latimer – USEPA Veronica Berounsky – URI Brian Sturgis – ASIS
Coastal and Barrier Network, Estuarine Nutrient Enrichment Workgroup	March 18, 2002	Final selection of monitoring variables for network-wide testing	Hilary Neckles – USGS Blaine Kopp – USGS Charles Roman – NPS NAC-CESU Scott Nixon – URI Barbara Nowicki – URI Gerald Pesch – USEPA Charles Strobel – USEPA Donald Cobb – USEPA

Acronyms: ASIS – Assateague Island National Seashore; CACO – Cape Cod National Seashore; COLO – Colonial National Historic Park; GATE – Gateway National Recreation Area; GEWA – George Washington Birthplace National Monument; NPS WRD – National Park Service Water Resources Division; NPS NAC-CESU – National Park Service North Atlantic Coast Cooperative Ecosystem Studies Unit; SAHI – Sagamore Hill National Historic Site; THST – Thomas Stone National Historic Site; URI – University of Rhode Island; US EPA – United States Environmental Protection Agency; URI – University of Rhode Island; USGS – United States Geological Survey; VIMS – Virginia Institute of Marine Science

Table 2. Characteristics of effective monitoring variables (after Jackson et al. 2000, NPS 2000b, Dale and Beyeler 2001, Kurtz et al. 2001)

Relevant to management concerns and ecological resources	
	Address monitoring questions of interest
	Have known linkage to ecological function or critical resource of interest
	Are at appropriate scale to answer specific monitoring questions
	Are integrative in space and time, so that the full suite of variables provides assessment of entire system of interest
Applicable for use in a monitoring program	
	Are easy and practical to measure
	Are non-destructive or low impact to measure without disturbing monitoring site
	Are measurable using standard, well-documented methods
	Generate data that are compatible with other systems
	Are cost-effective to measure
Responsive to anthropogenic stresses	
	Have known sampling and measurement error
	Have low natural variability
	Have known variability in time and space
	Are sensitive to anthropogenic stresses on the system or resource of interest, while having limited and documented sensitivity to other factors (i.e. to natural variation in ecosystem condition)
Interpretable and useful to environmental decision-making	
	Respond to stress in a predictable manner
	Are anticipatory: signal impending change in ecosystem before substantial degradation occurs
	Are linked to management decisions; predict changes that can be averted by management action, or document success of past actions
	Have known or proposed thresholds of response that delineate acceptable from unacceptable ecological condition
	Can be communicated to managers and the public

Table 3a. Candidate variables proposed for regional monitoring of estuarine nutrient enrichment. Summary of relevant data available from the NPS and other programs for Maryland and Virginia coastal parks. Refer to Appendix for more detailed information and references.

	Assateague (ASIS)	Colonial (COLO)	G. Washington (GEWA)
Agents of Change			
Watershed Land Use & Land Cover Mapping	Land use/land cover data are available for all Network Parks from the NOAA C-CAP. Also, national land cover data (15 land classes) are available from the MRLC Consortium from 1991 and 1992 imagery.		
	Additional land-use tracking proposed by eutrophication monitoring plan		
Inventory of Nutrient Point Sources	Nutrient point sources relevant to each park unit are inventoried and permitted by states and /or EPA under NPDES permitting laws.		
Atmospheric Deposition of Nitrogen	NADP monitoring of wet deposition of nutrients throughout the country. (++) Park unit has NADP station within its boundaries; (+) Park unit represented by nearby NADP station; (-) No NADP station in vicinity of park unit.		
	++	-	-
Ecosystem Responses			
Chlorophyll-*a*	NPS: monthly at 18 stations	CBNERR-VA: monthly monitoring on lower York R. VA DEQ: other portions of COLO are inadequately monitored for Vital Signs needs.	
Attenuation of PAR	NPA: K_d measured monthly at 18 stations	CBNERR-VA: monthly at 4 stations on lower York R. VA-DEQ: 6x/yr in the York R. & James R. but inadequate in COLO bays and tidal creeks.	
SAV Distribution	Mapping (with biomass estimates) conducted annually by R. J. Orth at VIMS		
Sediment Organic C			
Dissolved Oxygen	NPS: monthly at 18 stations & continuous at 3 stations	CBNERR-VA: continuous on York R.; ACB Citizens Monitoring: weekly along York R. & James R.; VA DEQ: other portions of COLO are inadequately monitored for Vital Signs.	ACB Citizens Monitoring: summertime weekly in Popes Creek. VA DEQ: 1 station in Popes Creek, 3 stations in Potomac R. in proximity to GEWA, 6x/yr.
Benthic Community Structure		VA DEQ: 6x/yr in York R. & James R., but inadequate in COLO bays and creeks.	CBP: quarterly in main stem of Chesapeake Bay, no stations in GEWA
Required Ancillary Data			
Temperature & Salinity	NPS: monthly at 18 stations & continuous at 3 stations; MD CBP Volunteer Monitoring: 30 nearshore stations, 2x/mo. April-Nov., otherwise monthly	CBNERR-VA: continuous and monthly monitoring on lower York R.; VA DEQ: other portions of COLO are inadequately monitored for Vital Signs needs.	ACB Citizens Monitoring: summertime weekly in Popes Creek. VA DEQ: 1 station in Popes Creek, 3 stations in Potomac R. in proximity to GEWA, 6x/yr.

Acronyms	ACB- Alliance for Chesapeake Bay; CBNERR-VA-Chesapeake Bay National Estuarine Research Reserve-Virginia; MD CBP-Maryland Coastal Bays Program; MRLC-Multi-Resolution Land Characteristics Consortium; NADP-National Atmospheric Deposition Program; NOAA C-CAP- NOAA, Coastal Change Analysis Program; NPDES-National Pollutant Discharge Elimination System; NPS-National Park Service; VA DEQ-Virginia Department of Environmental Qualtiy; VIMS-Virginia Institute of Marine Science.

Table 3b. Candidate variables proposed for regional monitoring of estuarine nutrient enrichment. Summary of relevant data available from the NPS and other programs for New York coastal parks. Refer to Appendix for more detailed information and references.

	Gateway (GATE)	Fire Island (FIIS)	Sagamore Hill (SAHI)
Agents of Change			
Watershed Land Use & Land Cover Mapping	Land use/land cover data are available for all Network Parks from the NOAA C-CAP. Also, national land cover data (15 land classes) are available from the MRLC Consortium from 1991 and 1992 imagery.		
		Suffolk, Nassau County land use tracking	
Inventory of Nutrient Point Sources	Nutrient point sources relevant to each park unit are inventoried and permitted by states and /or EPA under NPDES permitting laws.		
Atmospheric Deposition of Nitrogen	NADP monitoring of wet deposition of nutrients throughout the country. (++) Park unit has NADP station within its boundaries; (+) Park unit represented by nearby NADP station; (-) No NADP station in vicinity of park unit.		
	+	-	-
Ecosystem Responses			
Chlorophyll-*a*	NPS-JB: Weekly May-Sept. & monthly thereafter at 9-15 bay & 2 Atl. beach stations. IEC: Stations in NY/NJ Harbor relevant to SI and SH. Bi-weekly in summer, monthly thereafter. NYC DEP: 8 JB stations & 1 lower NY Harbor. Weekly May-Sept & 1-2x/month thereafter.	SSER: 20+ stations within Reserve boundary, 3-15x/yr.	
Attenuation of PAR			
SAV Distribution	Only known SAV is small bed at SH		
Sediment Organic C			
Dissolved Oxygen	NPS-JB: Weekly May-Sept. & monthly thereafter at 9-15 bay & 2 Atl. beach stations. 3 continuous stations will be established in 2002. IEC: Stations in NY/NJ Harbor relevant to SI & SH units. Bi-weekly in summer, monthly thereafter.	SSER: 20+ stations within Reserve boundary, 3-15x/yr.	FOB: weekly summertime measurements taken at 6a.m. at 2 stations in Cold Spring Harbor.
Benthic Community			
Required Ancillary Data			
Temperature & Salinity	NPS(All units): Weekly May-Sept. & monthly thereafter. IEC: Stations in NY/NJ Harbor and LI Sound relevant to SI & SH. Bi-weekly in summer & monthly thereafter. NYC DEP: 8 JB stations & 1 lower NY Harbor. Weekly May-Sept. & 1-2x/month thereafter.	SSER: 20+ stations within Reserve boundary, 3-15x/yr.	FOB: weekly summertime measurements taken at 6a.m. at 2 stations in Cold Spring Harbor.

Acronyms	FOB-Friends of the Bay; IEC-Interstate Environmental Commission (CT,NY,NJ); JB-Jamaica Bay Unit; MRLC-Multi-Resolution Land Characteristics Consortium; NADP-National Atmospheric Deposition Program; NOAA C-CAP- NOAA, Coastal Change Analysis Program; NPDES-National Pollutant Discharge Elimination System; NPS-National Park Service; NYC DEP-New York City Department of Environmental Protection; SH-Sandy Hook Unit; SI-Staten Island Unit; SSER-South Shore Estuary Reserve.

Table 3c. Candidate variables proposed for regional monitoring of estuarine nutrient enrichment. Summary of relevant data available from the NPS and other programs for New England coastal parks. Refer to Appendix for more detailed information and references.

	Cape Cod (CACO)	Boston Harbor Islands (BOHA)	Acadia (ACAD)
Agents of Change			
Watershed Land Use & Land Cover Mapping	Land use/land cover data are available for all Network Parks from the NOAA C-CAP. Also, national land cover data (15 land classes) are available from the MRLC Consortium from 1991 and 1992 imagery.		
	Barnstable County land-use tracking; additional land-use tracking proposed by NPS prototype monitoring plan		
Inventory of Nutrient Point Sources	Nutrient point sources relevant to each park unit are inventoried and permitted by states and /or EPA under NPDES permitting laws.		
Atmospheric Deposition of Nitrogen	NADP monitoring of wet deposition of nutrients throughout the country. (++) Park unit has NADP station within its boundaries; (+) Park unit represented by nearby NADP station; (-) No NADP station in vicinity of park unit.		
	++	+	++
Ecosystem Responses			
Chlorophyll-*a*	NPS: expected to be included in prototype monitoring protocol under development	MWRA: Weekly at 9 receiving-water stations May-Oct., fortnightly thereafter	
Attenuation of PAR		MWRA: Weekly at 9 receiving-water stations May-Oct. fortnightly thereafter	
SAV Distribution	MA DEP: Target mapping every 5 years	MA DEP: Target mapping every 5 years	
Sediment Organic C		MWRA: annual August survey	
Dissolved Oxygen	NPS: expected to be included in prototype monitoring protocol under development	MWRA: weekly at 9 receiving-water stations May-Oct., fortnightly thereafter; weekly at 5 former outfall stations in Boston Harbor throughout the year	
Benthic Community Structure		MWRA: annual August survey	
Required Ancillary Data			
Temperature & Salinity			
Acronyms	MA DEP-Massachusetts Department of Environmental Protection; MRLC-Multi-Resolution Land Characteristics Consortium; MWRA-Massachusetts Water Resource Authority; NADP-National Atmospheric Deposition Program; NOAA C-CAP- NOAA, Coastal Change Analysis Program; NPDES-National Pollutant Discharge Elimination System; NPS-National Park Service.		

Table 4. Summary of nutrient concentration monitoring conducted by the National Park Service and other monitoring programs for each of the North Atlantic coastal parks. Refer to Appendix for more detailed information and references on nutrient and other monitoring activities at network parks.

Park Unit	Nutrient Concentration Monitoring
ASIS	The National Park Service at ASIS monitors DIN, DIP, TN & TP monthly at 18 stations throughout Chincoteague and Sinepuxent Bays. MD Coastal Bay Program runs a volunteer monitoring that samples DIN & DIP at 30 near-shore stations. Sampling occurs two times per month from April – November and monthly thereafter.
COLO	Virginia Department of Environmental Quality monitors six times per year for 305(b) reporting. They analyze for a full suite of dissolved and particulate, organic and inorganic nutrients at a subset of tributaries (varies). The Virginia Chesapeake Bay National Estuarine Research Reserve conducts monthly monitoring of DIN & DIP in the lower York River.
GEWA	Virginia Department of Environmental Quality monitors six times per year for 305(b) reporting at One station in Popes Creek, and three in the Potomac River in proximity to GEWA. They analyze for a full suite of dissolved and particulate, organic and inorganic nutrients.
GATE	The National Park Service at GATE monitors DIP & NO2+3 in Jamaica Bay Unit only. The sampling frequency is approximately weekly from mid-May to September and approximately monthly thereafter. They collect at 9 to 15 bay stations and 2 Atlantic/Breezy Point beach stations. Interstate Environmental Commission conducts bi-weekly summer sampling of DIN, DIP, TN, TP and monthly during the rest of the year. Stations are located in NY/NJ Harbor and are relevant to the Staten Island Unit.
FIIS	The South Shore Estuary Reserve samples at over 20 stations within the reserve boundary (FIIS fall within this area). Samples are collected at each station from 3 to15 times per year and analyzed for a full suite of dissolved inorganic and organic nutrients (including Si) plus DOC and TOC.
SAHI	No nutrient concentration monitoring has been identified in this area, however the Friends of Oyster Bay Citizen Monitoring Program is considering the addition of nutrient sampling as part of their weekly summer sampling program.
CACO	The prototype protocol for estuarine nutrient enrichment at CACO is under development by the National Park Service. Data from the testing phase are under evaluation for including nutrient monitoring in the protocol.
BOHA	The Massachusetts Water Resources Authority monitors a full suite of dissolved and particulate, organic and inorganic nutrients at 8 stations in close proximity to park resources. Samples are collected every 1 or 2 weeks depending upon station and season.
ACAD	No nutrient concentration monitoring is ongoing for estuaries at ACAD.

Figure 1. North Atlantic park units.

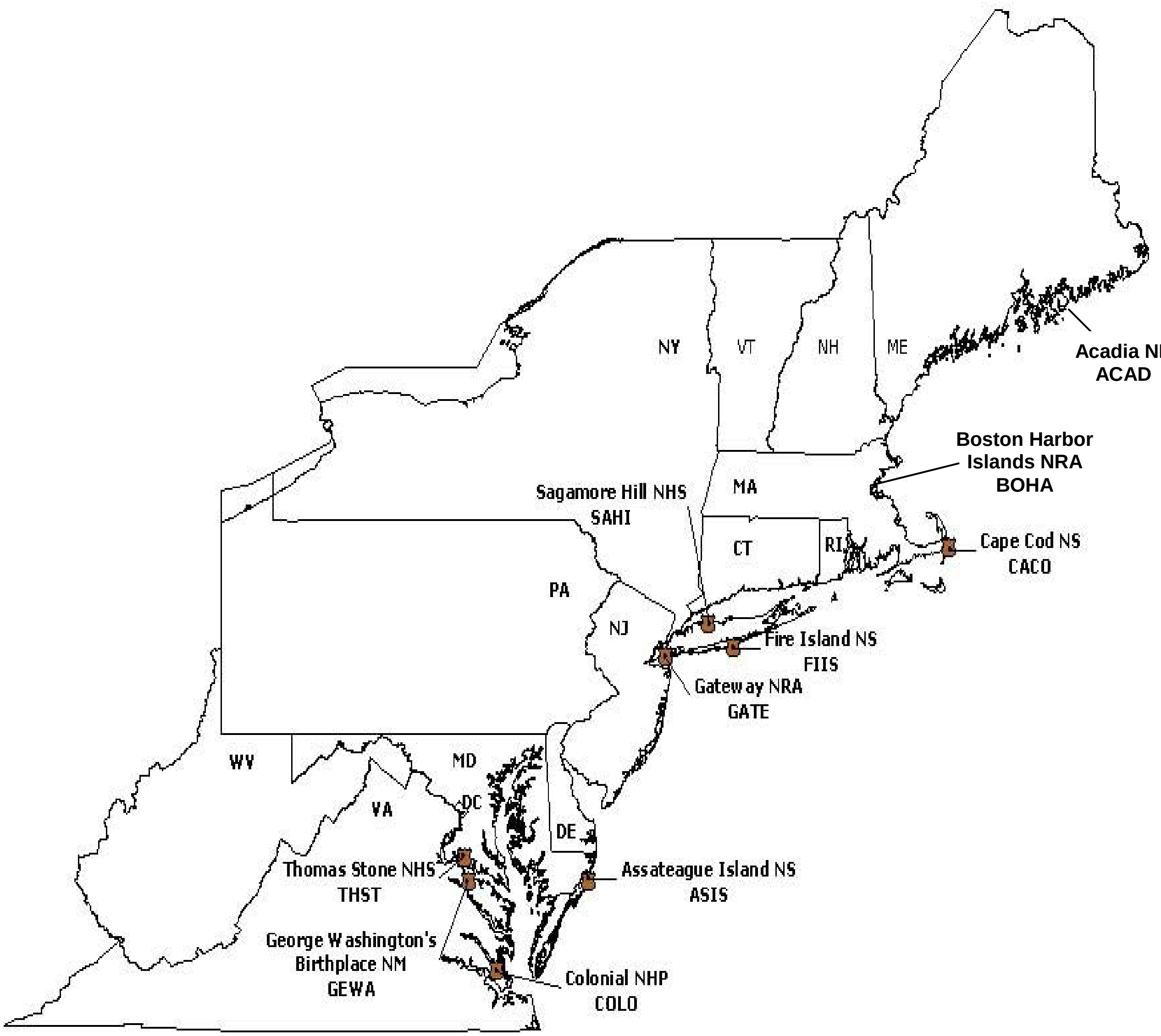
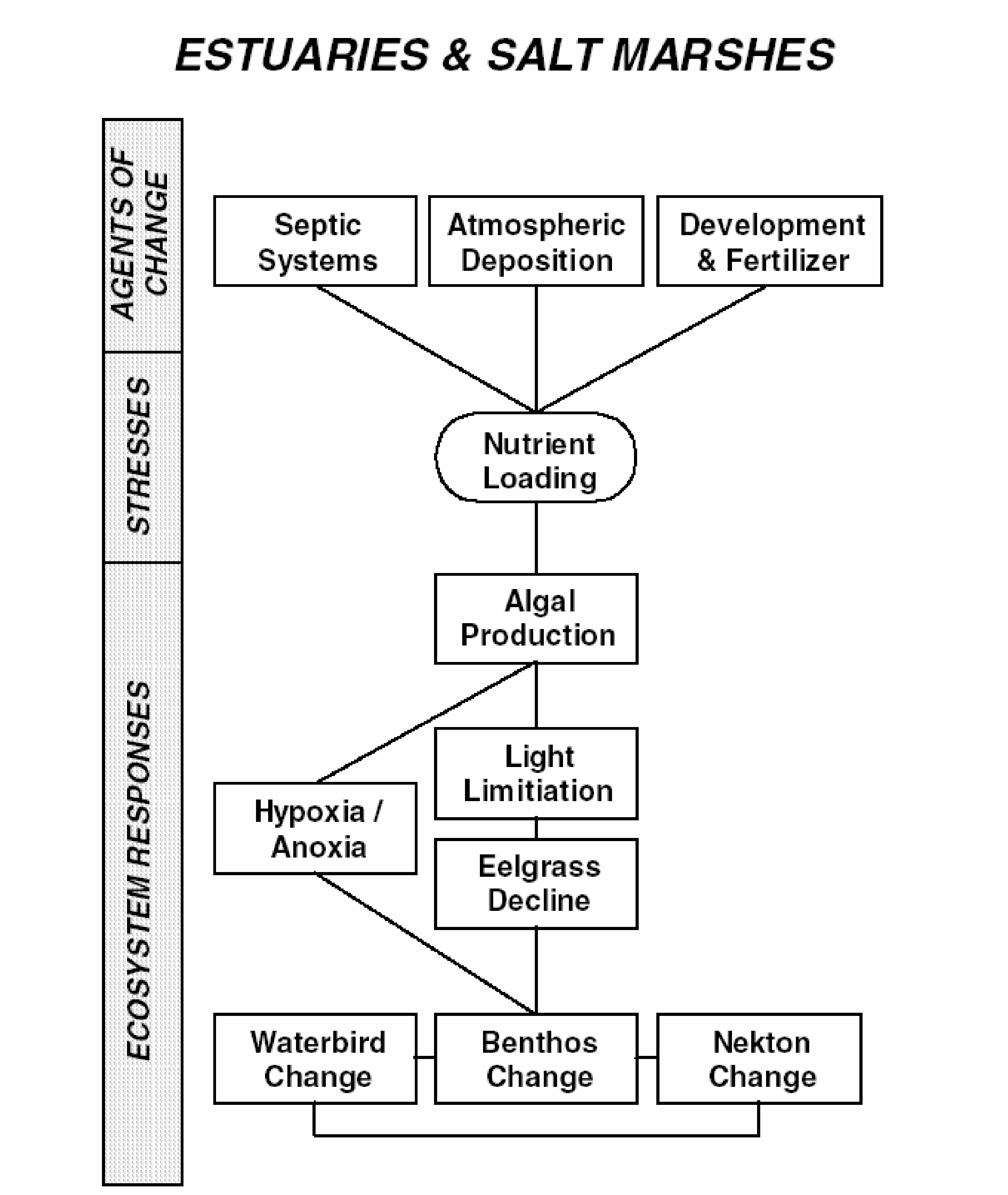


Figure 2. Conceptual model of estuarine ecosystem agents of change, nutrient load, and ecosystem response developed for the Cape Cod Prototype (from Roman and Barrett 1999).



Appendix:

Review of existing monitoring programs and activities within North Atlantic National Parks that are relevant to the development of Vital Signs indicators for estuarine nutrient enrichment.

Assateague Island National Seashore (ASIS)

Character of Park Estuarine Resources

Assateague Island National Seashore (ASIS) was established by Congress in 1965 to preserve the natural resources and recreational value of Assateague Island, Maryland and Virginia. The boundary of ASIS (Figure A-1) encompasses approximately 19,425 hectares. Over 60% of the area is oceanic and estuarine habitat, including Chincoteague and Sinepuxent Bays (NPS 2000a). As an undeveloped barrier island, land-use within the park has much less influence on the eutrophication status of these bays than does land use throughout the adjacent Maryland watersheds that drain into them.

The management and monitoring of estuarine natural resources at the park is a joint effort among many federal and state partners. The boundary of Assateague Island National Seashore encircles the National Park Service (NPS) holdings, the US Fish and Wildlife Service's Chincoteague National Wildlife Refuge (VA portion of Assateague Island), and Maryland's Assateague State Park. Further, Sinepuxent Bay and the Maryland portion of Chincoteague Bay are managed under the Maryland Coastal Bays Program (MCBP) as a National Estuary Program (NEP) estuary. The MCBP identified five major environmental problems facing the coastal bays: degraded water quality, loss of habitats, changes in living resources, unsustainable growth and development, and poorly planned recreational use of the bays (MCBP 1999). Of these, degraded water quality due to nutrient and sediment enrichment was identified as the most pressing environmental problem. Consequently, the MCBP developed a comprehensive eutrophication monitoring plan for the area (MCBP 1999). Over 70 existing and relevant monitoring programs within the coastal bays and their watersheds were reviewed for possible inclusion in the plan (MCBP 1998a). Implementation requires the continued participation of many of these monitoring partners (including National Park Service monitoring of estuarine water quality), and expanded or newly-created monitoring programs for many of the components. Implementation is coordinated by the Maryland Department of Natural Resources, Resource Assessment Service through a Monitoring Subcommittee of the Scientific and Technical Advisory Committee.

<u>Conceptual framework for MCBP monitoring:</u>

Three levels of monitoring are identified in the MCBP Eutrophication Monitoring Plan: landscape monitoring and management action tracking (level I), stressor monitoring (level II), and response monitoring (level III). Although the monitoring plan is thorough for current needs and adaptable to future ones, a notable weakness is the exclusion of a significant portion of ASIS estuarine habitat because of the political boundary between Maryland and Virginia. The MCBP Eutrophication Monitoring plan stations maps are appended to this section.

Landscape Monitoring

Land use and land cover data are available from the NOAA C-CAP Coastal Change Analysis Program. Also, national land cover data (15 land classes) are available from the Multi-Resolution Land Characteristics Consortium from 1991 and 1992 imagery.

In addition, several sources of land use characterization data are identified in the eutrophication monitoring plan, but are not yet being compiled in a meaningful format for tracking landscape level changes. Among these, rates of nutrient application are tracked by the Worcester County Cooperative Extension Service (CES) for some of the agricultural land. Crop acres and yields are compiled by the MD Office of Agricultural Statistics, and animal populations and manure production may be estimated using data from Worcester CES and Worcester Soil Conservation District.

Nutrient Stressor Monitoring

A National Atmospheric Deposition Program (NADP) station (MD18) is located within the boundary of ASIS, and has been in operation since the year 2000. The NADP protocol calls for weekly integrated samples to be collected and analyzed for dissolved inorganic nitrogen species. There is no permanent ongoing monitoring of groundwater loading, but USGS studies of groundwater discharge and nitrate loading have been conducted (Dillow and Greene 1999). Likewise, there is currently no ongoing monitoring of nutrient flux via surface water. There is, however, one USGS stage-discharge monitoring station in operation, and an expanded network has been proposed. This is scheduled to include event-triggered sampling for water chemistry. The bulk of the non-point sources of nitrogen to the Maryland Coastal Bays come from agricultural runoff (51%) and atmosphere deposition (32%)(MCBP 1998b). For point sources, there are five sewage treatment plants and three permitted industrial discharges monitored under the National Pollutant Discharge Elimination System (NPDES) and Maryland Department of the Environment (MDE) Point Source Discharge Permits.

Ecosystem Response Monitoring

<u>Water quality</u>

The National Park Service has an extensive water quality monitoring program at ASIS dating back to 1987. Eighteen stations are sampled monthly throughout the year for a suite of water quality measures including nitrate+nitrite, ammonium, phosphate, silica, total nitrogen (not filtered), total phosphorus (not filtered), silica, total suspended solids, cholorphyll-*a*, *b*, and *c*, pheophytin-*a*, temperature, dissolved oxygen, specific conductance, pH, Secchi depth, light attenuation, and wind speed and direction. Half of the eighteen stations are in MD waters and half in VA. Station locations were selected primarily to insure that each embayment would be sampled, with attention to confluence areas around major tributaries. Secondary station selection criteria targeted areas with documented water quality problems; tertiary criteria addressed proximity to important living resources, habitats and related monitoring sites; quartenary criteria examined suitability of historical monitoring sites. The final suite includes representative stations from both near-shore and mid-channel areas.

In addition to discrete monthly monitoring, three permanent automated monitoring stations are in place. At these stations, tide height, dissolved oxygen, total suspended solids, temperature, conductivity, and pH are recorded hourly.

Review of additional ecosystem response monitoring programs

MD Coastal Bays Program Volunteer Monitoring

Maryland Coastal Bays Program established a volunteer water quality monitoring program in 1997. This program monitors approximately 30 sites in the Maryland portion of the coastal bays. These sites consist of a targeted list of tidal creek, canal, cove, and harbor sites that are accessible from the shore. Monitoring variables include salinity, pH, chlorophyll-*a*, and dissolved inorganic nutrients. The stations are visited two times per month from April through November, and monthly thereafter.

EMAP, Coastal 2000, National Coastal Assessment.

In 1993, two hundred sites were sampled in a stratified random sampling design, integrated with the Mid-Atlantic assessment. In 2000, MD DNR was awarded a 5-year grant from the US EPA to conduct assessments of the DE and MD coastal bays using protocols developed by the US EPA Environmental Monitoring and Assessment Program (EMAP) (54 water quality stations, and 29 fish trawl and seine stations). Among the suite of variables measured were dissolved oxygen, salinity, pH, temperature, depth, light attenuation, turbidity, transmissivity, Secchi depth, nutrients (full suite of nitrogen, phosphorus , and silica species), chlorophyll-*a*, phytoplankton species, benthos, neckton, submerged aquatic vegetation, macroalgae, and exotic species.

Other ecosystem response monitoring programs include:

- Annual mapping of the distribution and biomass of submerged aquatic vegetation in Chincoteague Bay (R. Orth, Virginia Institute of Marine Science).
- Macroalgae monitoring by the Maryland Department of Natural Resources (DNR). This program is starting its third year and the monitoring protocol is currently under review. Last year, over 600 stations in Maryland waters were sampled quarterly for species composition and biomass.
- Harmful/nuisance phytoplankton blooms. Maryland DNR monitors fifteen stations for the presence of *Aureococcus* and *Pfiesteria*. Monitoring in 1999 and 2000 was conducted between May and July with some additional monitoring in the fall of 2000.
- Nekton monitoring. Maryland DNR monitors 20 trawl stations monthly between April and October and 19 fixed seine stations in June and September. In addition, fish health stations were added as part of the comprehensive *Pfiesteria* monitoring program.

- Fish Kill monitoring program. Maryland Department of the Environment maintains records on reported fish kills.

Figure A-1. National Park Service Visitor Map of Assageague Island National Seashore.

Colonial National Historical Park (COLO)

Character of Park Estuarine Resources

Colonial National Historical Park (COLO, Figure A-2) consists of two significant land holdings, the Yorktown and Jamestown Units (Figure A-3), connected by a narrow traffic corridor, the Colonial Parkway. In total, the park holds 3,764 ha of land within three separate local political jurisdictions: York County, James City County, and the City of Williamsburg. The park is located adjacent to a rapidly developing urban/suburban area. Other key park neighbors include a Coast Guard Reserve Training Center and three US Navy facilities (a weapons station, a supply center, and a fuel farm). The Yorktown unit sits across the York River from the Virginia Institute of Marine Science (VIMS), and is characterized by sandy /gravely shore in an urban setting. The estuarine habitat is dominated by the lower York River, but the park also abuts a tidal creek estuary to the east, the West Branch of Wormley Creek. The Jamestown unit occupies all of Jamestown Island on the northeast bank of the lower James River. The estuarine habitat at Jamestown is dominated by the lower James River on one side, and by Sandy Bay, the Back River, and The Thorofare on the other. Jamestown Island, which is managed jointly by NPS and the Association for the Preservation of Virginia Antiquities (APVA), is low in elevation and dominated by wetlands and tidal creeks. The Jamestown unit is itself undeveloped; however, the Powhatan Creek watershed, which drains into Sandy Bay and The Thorofare, is under tremendous development pressure. A nutrient reduction strategy and watershed management plan was drafted in 2001 to address threats posed by additional development (James City County 2001). The Colonial Parkway is a narrow corridor of park property passing over seven tidal creek systems. These are (from Jamestown to Yorktown) Powhatan Creek, Mill Creek, College Creek, Halfway Creek, King Creek, Felgate’s Creek, and Indian Field Creek.

Currently, NPS conducts no ongoing estuarine habitat or water quality monitoring at COLO. NPS has, however, begun developing a long-term surface water quality monitoring program (Project Statement COLO-N-601.503). Part of this planning effort included a review of relevant water quality monitoring activities within or near the park that were archived in the EPA’s Storage and Retrieval (STORET) data archive. Those sites with immediate relevance to the park’s estuarine habitat and water quality are identified on the station map (figure attached). Of 26 stations identified by the data search, only eight had good multi-year data for water quality. Measured parameters were not consistent between stations or sampling events, but typically included most of the following: temperature, conductivity, dissolved oxygen and dissolved inorganic and total nitrogen and phosphorus. Overall, the internal review concluded that there are too few stations in and near COLO, and too few measured parameters, to adequately describe water quality within the park (C. Rafkind, unpublished). The bulk of monitoring activities in park environs are conducted along the major rivers flowing past Jamestown and Yorktown park units. In 2000, the Commonwealth of Virginia prepared nutrient reduction strategies for both the James and York Rivers (VA 2000a, VA 2000b). Nutrient loading to these rivers is well understood; point sources are directly monitored and in situ nutrient concentrations are measured by the Virginia Department of Environmental Quality.

Landscape Monitoring

Land use and land cover data are available from the NOAA C-CAP Coastal Change Analysis Program. Also, national land cover data (15 land classes) are available from the Multi-Resolution Land Characteristics Consortium from 1991 and 1992 imagery. National Wetlands Inventory Data, published by the US Fish and Wildlife Service, is available for this area, but comes from photography taken between 1970 and the early 1990s.

Nutrient Stressor Monitoring

No NADP site is located in the immediate area. The closest is MD18 at ASIS or VA24 in Prince Edward County, VA. However, the Atmospheric Integrated Research Monitoring Network (AIRMoN) is a network of the NADP that collects daily deposition samples. The closest AIRMoN station is number MD15 on Smith Island in the main stem of the Chesapeake Bay. It is operated by the US EPA and the Chesapeake Bay Program. Additionally, the Virginia Chesapeake Bay National Estuarine Research Reserve (CBNERR-VA), located across the York River at VIMS, does conduct continuous meteorological/weather monitoring and is interested in the possibility of expanding its program to include atmospheric deposition monitoring.

Ecosystem Response Monitoring

<u>Chesapeake Bay National Estuarine Research Reserve, Virginia</u>

The CBNERR-VA has conducted monthly discrete water quality monitoring at a minimum of four stations along the lower York River since 1997. Parameters for this program (NERR 2001) include chlorophyll-*a*, Secchi depth, diffuse attenuation coefficient of photosyntheticly active radiation (PAR) and nutrients (ammonium, nitrate, nitrite, and phosphate). The reserve is planning to add additional nutrients species to their suite of analytes in the near future (particulate nitrogen and phosphorus, total dissolved nitrogen and phosphorus, particulate and dissolved organic carbon, and silica). These discrete samples support continuously-operating automated sampling boys at the same four stations. Data sonds at each station log temperature, salinity, turbidity, total suspended solids, dissolved oxygen, and pH.

<u>Virginia Department of Environmental Quality, Office of Water Quality Assessment</u>

Numerous permanent stations on both the lower York and lower James Rivers are visited a minimum of six times per year. In coordination with the EPA National Coastal Assessment, probabilistic sampling was scheduled to be added for the 2002 sampling year. This program interfaces with the Chesapeake Bay Program and addresses many DEQ and Bay Program variables: pH, dissolved oxygen, temperature, salinity, Secchi depth, diffuse attenuation coefficient of PAR, total suspended solids, nitrate, nitrite, ammonium, phosphate, total nitrogen, total phosphorus, silica, chlorophyll-*a*, species composition of phytoplankton and zooplankton, benthic fauna, five-day biochemical oxygen demand, chemical oxygen demand, and bacteriological monitoring.

Review of additional monitoring programs

Other ecosystem response monitoring programs include:

- Annual mapping of the distribution and biomass of submerged aquatic vegetation (R. Orth, VIMS).
- VIMS Juvenile Fish and Blue Crab Trawl Survey. Started in 1955, currently occupies 60 stations monthly.
- Remote sensing program for chlorophyll-*a* throughout the Chesapeake using Ocean Data Acquisition System (ODAS) satellite sensors since 1986, then SEAWIFS aircraft simulator (SASII) instruments since 1997. Mapping is incomplete in tributaries.
- The Alliance for Chesapeake Bay (ACB) Citizen's Monitoring Program (CBCMP) began in 1985 and monitors sites along the York and James Rivers near the park. Shoreline sites are monitored weekly for DO, pH, and turbidity. Limited nutrient data have also been collected on occasion.
- The VIMS "Shoal Run" occupies a station near COLO (Yorktown end) and measures dissolved inorganic nitrogen and phosphorus, total suspended solids, chlorophyll-*a*, and the diffuse attenuation coefficient of PAR.
- VA Chesapeake Bay Program main stem phytoplankton monitoring for nuisance/harmful species since 1985.
- VA Chesapeake Bay Program main stem benthic monitoring. The state of Virginia and the US EPA Chesapeake Bay program have cooperatively monitored benthic fauna and sediment composition in the VA portions of the main stem and tributaries since 1985. This includes the lower York and James Rivers, but not the small tidal creeks of COLO. A probability-based sampling design was layered over the fixed station approach starting in 1994.

Figure A-2. National Park Service Visitor Map of Colonial National Historical Park

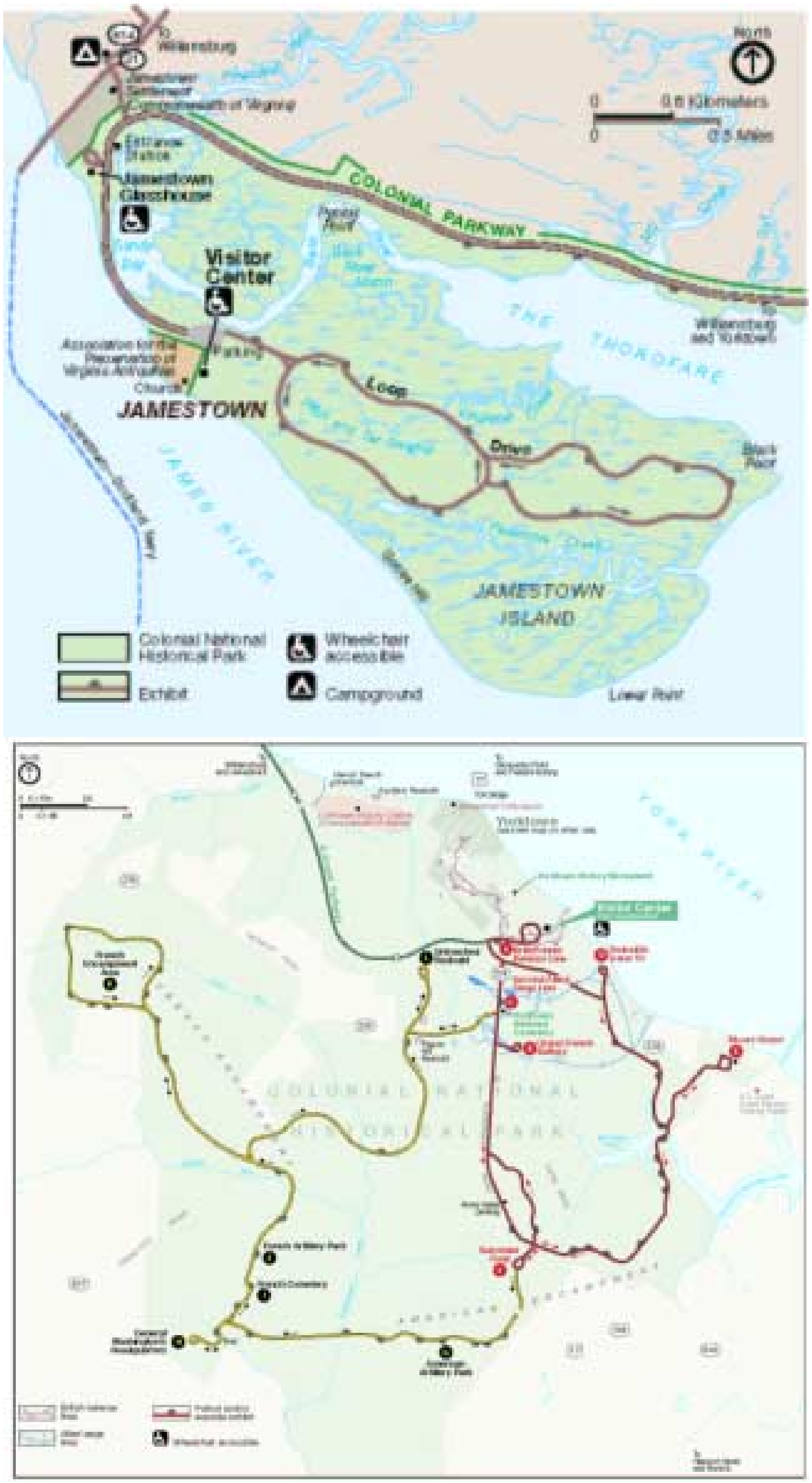


Figure A-3. National Park Service Visitor Maps of Colonial National Historical Park, Jamestown and Yorktown Units.

George Washington Birthplace National Monument (GEWA)

Character of Park Estuarine Resources

George Washington Birthplace National Monument (GEWA) is a 223-ha unit of the National Park Service located along the tidal reaches of the Potomac River in Westmoreland County, Virginia (Figure A-4). GEWA lies within the Potomac River watershed, and consequently, the greater Chesapeake Bay watershed. The Potomac shoreline, which delineates the northern boundary of the monument and also the border between Virginia and Maryland, has a tidal range of approximately 1 meter at GEWA, and a salinity range of 0.5 to 17‰ (Belval et al. 1997 and citations therein). Erosion along the Potomac shoreline is severe and represents significant threats to the monument. The low terrace soils of poorly-drained silty sand and clay form steep embankments, 5-7 m high, along the river. These are currently receding at the rate of 30-100 cm per year (R. Morawe personal communication). Three small sub-basins drain into the Potomac at GEWA. These are Popes Creek, Bridges Creek, and a third unnamed creek. The combined area of these sub-watersheds is approximately 5,463 ha (Belval et al. 1997). The largest of these (and most significant to GEWA) is Popes Creek. Land use in the three sub-basins is largely agricultural, and park abutters raise cattle (which are allowed to wade in the creeks), and make use of bio-solids to fertilize their fields. Since there are no known point sources for bacteriological contamination within Popes Creek, farming and other non-point sources are most likely responsible for the fecal coliform contamination that has kept the creek closed to shellfishing since 1972 (Belval et al. 1997). Nonetheless, results of sediment contaminant studies (organics and metals) indicate that Popes Creek is among the most pristine creeks in the Chesapeake (R. Morawe personal communication), and the system is used as a reference location for numerous studies considering the effects of agricultural runoff on receiving waters and their geochemistry (see Wilde et al. 2000 and references therein).

Landscape Monitoring

Land use and land cover data are available from the NOAA C-CAP Coastal Change Analysis Program. Also, national land cover data (15 land classes) is available from the Multi-Resolution Land Characteristics Consortium from 1991 and 1992 imagery. National Wetlands Inventory Data, published by the US Fish and Wildlife Service, is available for this area, but comes from photography taken between 1970 and the early 1990s.

Nutrient Stressor Monitoring

No NADP stations are located within the boundary of GEWA. The closest NADP sites are MD13 in Wye, MD, and VA00 in Charlottesville. However, the Atmospheric Integrated Research Monitoring Network (AIRMoN) is a network of the NADP that collects daily deposition samples. The closest AIRMoN station is number MD15 on Smith Island in the main stem of the Chesapeake Bay. It is operated by the US EPA and the Chesapeake Bay Program.

There is no permanent ongoing monitoring of groundwater loading, but there is a USGS gauging well near the park. Within the park, there are an old shallow dug well and a modern production well for park use. Limited groundwater quality data are available for the monitoring well from the 1970's and currently from the GEWA production well (unpublished files USGS VA District Office, Belval et al. 1997). There was also a 1944 study of groundwater quality (from a spring at GEWA) indicating elevated nitrogen concentrations (Sinnott 1969). There are four permitted point-source discharges in Virginia within 3 miles of GEWA that are monitored under the National Pollutant Discharge Elimination System (NPDES). Only one of these, the Town of Colonial Beach STP, is a major discharger (2,000,000 gal/d). The rest are permitted for between 2,000 and 20,000 gallons per day of sewage effluent.

Ecosystem Response Monitoring

Virginia Department of Environmental Quality, Office of Water Quality Assessment

The streambed of the Potomac River falls within the state boundaries of Maryland and is monitored by that state. Tributary creeks and streams originating in Virginia, however, are monitored by the Virginia Department of Environmental Quality (VA DEQ) for federal Clean Water Act compliance. Starting in July 1997, a single station was added in Popes Creek to the list of VA DEQ monitoring stations (VA DEQ station number 1APOP000.38). It is sampled six times per year for a large suite of variables including the following: pH, dissolved oxygen, temperature, salinity, total suspended solids, nitrate, nitrite, ammonium, phosphate, total nitrogen, total phosphorus, sediment organic matter, and bacteriological monitoring. There is another DEQ station farther upstream at the VA Route 3 bridge.

State of Maryland

Maryland's basic statewide water monitoring activities are conducted principally by two agencies. Water monitoring programs within the Department of the Environment (MDE) address regulatory issues (e.g., permit compliance and modeling, evaluation of water quality standards, shellfish sanitation, Total Maximum Daily Loads) while those programs within the Department of Natural Resources (DNR) address water quality and aquatic resource issues. Since 1984, the EPA Chesapeake Bay Program has funded the State's Water Quality Monitoring efforts in the main stem bay. Two Potomac River stations within the vicinity of GEWA are maintained for federal Clean Water Act compliance. These include station XDC1706 at the US Route 301 bridge, and station MLE2.2 at Ragged Point. A full suite of dissolved organic and inorganic nutrients are monitored monthly at these stations as well as pH, temperature, chlorophyll-*a*, salinity, and Secchi depth. Phytoplankton community structure is examined monthly at a site upstream of GEWA at Indian Head; however this is over 50 km away. Benthic community structure and sediment organic matter are monitored annually using both fixed stations and probability-based sampling throughout the Potomac River. None of the fixed benthic stations are located directly adjacent to GEWA, but there are five stations within 20 km of GEWA: stations 43, 44,47, 51, and 52.

Review of additional monitoring programs

Other ecosystem response monitoring programs include:

- Annual mapping of the distribution and biomass of submerged aquatic vegetation (R. Orth, VIMS).

- Remote sensing program for chlorophyll-*a* throughout the Chesapeake using Ocean Data Acquisition System (ODAS) satellite sensors since 1986, then SEAWIFS aircraft simulator (SASII) instruments since 1997. Mapping is incomplete in tributaries.
- Alliance for CB Citizens Monitoring Program (ACBCMP). One site is located within Popes Creek at GEWA (since 1991), one site is approximately 4 miles downstream in the Potomac River, and one approximately 20 miles upstream. ACBCMP conducts weekly summertime monitoring for temperature, salinity, pH and dissolved oxygen.
- Chesapeake Bay Program main stem phytoplankton monitoring for nuisance/harmful species since 1985.

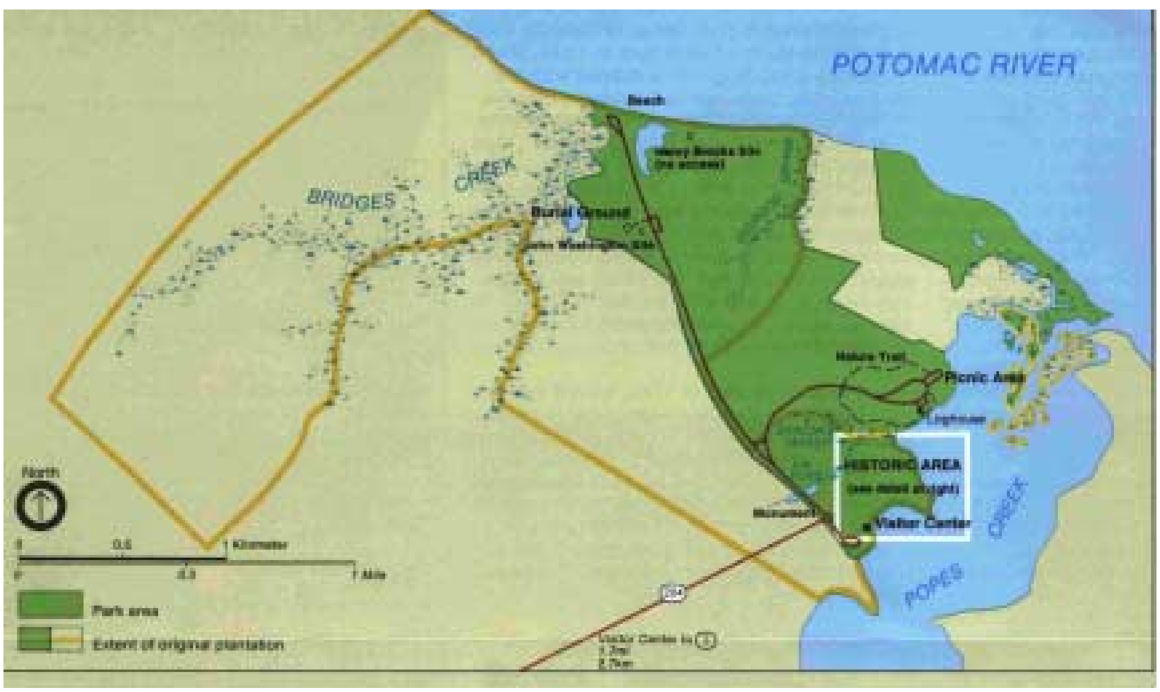


Figure A-4. National Park Service Visitor Map of George Washington Birthplace National Monument.

Gateway National Recreation Area (GATE)

Character of Park Estuarine Resources

Gateway National Recreation Area (GATE) consists of 10,783 hectares of coastal uplands, freshwater ponds, marshes, bays, beaches, and mudflats. Established in 1972, it is divided into four geographically separate units (Figure A-5) that constitute some of the largest and most significant natural areas remaining in the metropolitan New York City area. They include the Jamaica Bay/Breezy Point unit, the Sandy Hook unit, and the Staten Island unit.

Jamaica Bay and Breezy Point are considered separate units of GATE in the enabling legislation of 1972, but are generally treated as districts within a single unit (since Breezy Point constitutes the ocean-side barrier of Jamaica Bay). Three bathing beaches are located along Breezy Point district (Breezy Point Tip, Fort Tilden and Jacom Riis Park). The Jamaica Bay Wildlife Refuge district consists of 3,689 ha of marsh, wetlands, ponds and forested areas (Muzio and Rubel 1993). It is surrounded by the densely urban New York City boroughs of Brooklyn and Queens, and by the Rockaway Peninsula. Jamaica Bay's estuarine waters are heavily impacted from roadway stormwater runoff, wastewater and sewage treatment plant (STP) effluent, raw sewage from combined sewage overflows (CSOs), landfill leachate, and contaminants from JFK International Airport. STPs discharge an average of approximately $3.2x10^8$ gal/day directly into Jamaica Bay, and over 2000 CSOs in Jamaica Bay become active with even modest amounts of rainfall (G. Frame, personal communication). In addition to eutrophication concerns, marsh loss and coastal sea level rise present a clear and pressing threat to this ecosystem (NPS 2001).

The Sandy Hook Unit is a 10-km long peninsula attached to the mainland of the state of new Jersey, 26 km due south of Manhattan. 680 ha in size, Sandy Hook varies in width from 100 m to 1.5 km, and has approximately 10.5 km of ocean shoreline (Muzio and Rubel 1993). It is heavily influenced by the Atlantic Ocean as well as the Hudson River and the Navesik River. Sand transport and shoreline stabilization are significant issues for this unit of GATE.

The Staten Island Unit is located in Lower New York Harbor and, like the Sandy Hook Unit, is heavily influence by both the Hudson River and Atlantic Ocean. It is located on Staten Island's southeast shore and consists of an approximately five-mile stretch of contiguous beach (Great Kills Beach, Oakwood Beach, New Dorp Beach, Midland Beach and south Beach). Extending landward of the beaches are Miller Field and Fort Wadsworth. The northern extent of the Unit is located in Fort Wadsworth at the Verrazano Narrows Bridge, and the southern end is Crookes Point at Great Kills Harbor. Although enabling legislation designated this stretch of beach as part of GATE, exact park boundaries are vague, and some of the beach property is still under city ownership and control. Hoffman and Swineburn Islands, also part of GATE, are functionally associated with the Staten Island Unit.

All submerged lands within one quarter mile of any Park-owned shoreline are explicitly included in the enabling legislation for GATE. In New Jersey, however, the state claims ownership of the bottom, and consequently GATE does not regulate submerged lands at the Sandy Hook Unit.

Landscape Monitoring

Land use and land cover data are available from the NOAA C-CAP Coastal Change Analysis Program and the Multi-Resolution Land Characteristics Consortium. For the latter, mapping is available from 1991 and 1992 imagery, and land is classified into 15 classes.

Nutrient Stressor Monitoring

There are no NADP or AIRMoN stations for monitoring atmospheric deposition of nutrients in the immediate vicinity of GATE. The closest NADP site is NY99 at West Point, so estimates for deposition at the park would necessarily rely on NADP data contoured from all the regional sites. For point source discharges, National Pollutant Discharge Elimination System (NPDES) permits and compliance monitoring data are available from the New York State Department of Environmental Conservation. There are four major permitted STPs discharging into Jamaica Bay, with an average daily discharge of $3.2x10^8$ gal/day, and another STP that discharges adjacent to the Staten Island Unit. Monthly monitoring reports are available directly from the New York City Department of Environmental Protection (NYC DEP) Bureau of Wastewater Treatment. Additionally, NYC DEP has a hydrodynamic model for storm water discharge into Jamaica Bay (SWM).

Ecosystem Response Monitoring Programs

<u>Water quality</u>

GATE initiated a water quality monitoring program in 1981, and has maintained a consistent sampling regimen for a network of up to 30 stations since 1997 (NPS 2000b). As a National Recreation Area, Gateway's monitoring program is focused on public health concerns for "contact recreation." This is particularly true for the Sandy Hook and Staten Island Units, where the program is exclusively bacteriological in nature. Monitoring is conducted weekly from mid-May to September and approximately monthly thereafter at six stations in the Sandy Hook Unit, eight stations in the Staten Island Unit, and at 9-15 bay stations and 2 Atlantic beach stations in the Jamaica Bay/Breezy Point Unit. Additionally, the park monitors the following environmental parameters in Jamaica Bay: chlorophyll-*a*, salinity, dissolved oxygen, pH, temperature, Secchi depth, nitrate plus nitrite, and orthophosphate.

In addition to this discrete sampling program, three permanent automated monitoring stations are scheduled for deployment this year in Jamaica Bay through a cooperative agreement with Crusader Technologies. These will include sensors for temperature, pH, turbidity and dissolved oxygen. They may also include fluorometers for measuring chlorophyll-*a*, but are not scheduled to include salinity/conductivity sensors.

The Interstate Environmental Commission (IEC) also monitors water quality within the park. Their program includes 67 stations (33 long term) in NY/NJ Harbor and Long Island Sound (station map attached) with bi-weekly sampling during the summer and monthly during the rest of the year. Their suite of variables includes temperature, salinity, dissolved oxygen, chlorophyll-*a*, biochemical oxygen demand, turbidity, total organic carbon and a full suite of organic and inorganic nitrogen and phosphorus species.

The third major monitoring program relevant to GATE is conducted by the New York City Department of Environmental Protection. Eight stations (site maps attached) are monitored in Jamaica Bay, one at the Hudson River Narrows (representative of the Staten Island Unit unit), and several in lower NY Harbor (but north of the Sandy Hook Unit). The stations are sammpled weekly from mid-may through September, and once or twice per month throughout the rest of the year. Monitoring variables include temperature, salinity, pH, dissolved oxygen, chlorophyll-*a* and Secchi depth.

Benthos/neckton monitoring

GATE and the US Fish and Wildlife Service have conducted the Jamaica Bay Fisheries Survey since 1985. This survey includes 15 otter trawl sites, nine gill net sites, and six beach seine sites. The monitoring frequency is intermittent, but occurs approximately monthly (NPS 1991).

Other ecosystem response monitoring programs and information

New York / New Jersey Harbor is National Estuary Program (NEP) estuary, and all the units of GATE fall within the NEP study boundaries. Additionally, the NOAA system of National Estuarine Research Reserves (NERRs) includes a Hudson River NERR, which has land holdings approximately 20 miles upriver from the Staten Island unit. In addition to NPS monitoring, natural resources are monitored by the City of New York through their Harbor Survey Program, and the Interstate Environmental Commission (a collaboration between the states of New York, New Jersey and Connecticut and formerly called the Interstate Sanitation Commission). There are voluminous descriptions of research programs and monitoring programs for GATE in general, and Jamaica Bay in particular. The most notable sources of additional information and monitoring data come from the Jamaica Bay Ecosystem Restoration Team, and EMAP Coastal 2000. The latter conducted a probability-based survey of Jamaica Bay in 2001. Also, HydroQual Inc. has produced a Jamaica Bay Eutrophication Model. The NY/NJ Harbor Estuary Program has drafted a Comprehensive Conservation and Management Plan for this estuary (NY/NJ HEP 1996), which includes a mandate to develop a monitoring strategy for nutrients and eutrophication.

Figure A-5. National Park Service Visitor Map of Gateway National Recreation Area.

Fire Island National Seashore (FIIS)

Character of Park Estuarine Resources

Fire Island National Seashore (FIIS) is a 7,810-ha park on the South Shore of Long Island, New York (Figure A-6). Approximately 4,452 ha of this area are submerged lands in Great South Bay and Moriches Bay (80%) and the Atlantic Ocean (20%). Not included in the above area, but within the boundary of FIIS, is the Smith Point County Park located at the eastern end of Fire Island. At the western end of Fire Island, outside the park boundary, is the Robert Moses State Park. The character of FIIS is varied, and includes both wilderness area (Otis Pike Wilderness Area) and 17 local communities. These are largely summer communities since ferry service is only in operation from May to October. However, FIIS is situated only 55 miles from downtown Manhattan, and lies in the midst of the highly urbanized and suburbanized northeast seaboard, one of the most densely populated regions in the nation. Consequently, land-use within the park has much less influence upon the eutrophication status of Great South Bay and Moriches Bay than does the land use throughout the larger Long Island watersheds that drain into them. Most of the tidal exchange for GSB occurs through the Fire Island Inlet (SSER 2000). Groundwater constitutes 11% of the fresh water supply to Great South Bay (Pluhwoski and Kantrowitz 1964, SSER 2000), and groundwater concentrations of nitrogen have increased with upland development in non-sewered areas (Leamond et al. 1992). Atmospheric deposition constitutes 26% of the nitrogen load to Great South Bay (Schlenk and Wise 1999 as cited in SSER 2000), and the remainder comes from surface water and point source discharges. The National Estuarine Eutrophication Assessment (Bricker et al. 1999) lists Great South Bay as exhibiting high eutrophic conditions. Factors contributing to this listing include high levels of chlorophyll-*a*, moderate loss of submerged aquatic vegetation, and moderate nuisance algal blooms.

In 1993, the New York State Legislature created the South Shore Estuary Reserve (SSER) and the South Shore Estuary Reserve Council to manage it. The SSER extends both to the east and west of FIIS, including all of the southern coastal embayments on Long Island from West Bay in Hampstead to Shinnecock Bay in South Hampton. Although SSER is not a National Estuary Program estuary, its organization and resource-management strategies are consistent with those of the NEP. The SSER Council was tasked with developing a Comprehensive Management Plan for the reserve. As a component of its management plan, the Council commissioned a coordinated ecosystem monitoring strategy (SSER 2000). The SSER Council is formed of representatives from the state, adjacent cities, town, villages, counties, and interest groups. Enacting legislation did not, however, explicitly allow for participation by the National Park Service, and FIIS had not been represented as a council member or designee (SSER 2001).

Landscape Monitoring

Land use and land cover data are available from the NOAA C-CAP Coastal Change Analysis Program. Also, national land cover data (15 land classes) is available from the Multi-Resolution Land Characteristics Consortium from 1991 and 1992 imagery. The planning agencies for Suffolk County and Nassau County track land use, and, in particular, track the proportion of the counties covered by impervious surfaces. Every five years, New York State Department of Environmental Conservation (NYS DEC) conducts aerial photographic surveys for wetland delineation.

Nutrient Stressor Monitoring

There are no NADP or AIRMoN stations located in close proximity to FIIS to track atmospheric deposition of nutrients at the park. Estimates for deposition at the FIIS would necessarily rely on NADP data contoured from all the regional sites.

Point source loading of nutrients to SSER is traceable through National Pollutant Discharge Elimination System (NPDES) permits and compliance monitoring data, available from NYS DEC. Effluent volume and quality are reported to the state in monthly Discharge Monitoring Reports.

Surface water loading of nutrients used to be monitored by the USGS, however nutrient concentration monitoring in streams and tributaries flowing into GSB was abandoned by the Survey in 1996. Water stage in streams continues to be monitored by the USGS, and stage-discharge relationships are maintained for eight of the tributaries emptying into the SSER. NYS DEC conducts Rotating Intensive Basin Surveys (RIBS) of stream water quality (including nutrients). Together with USGS flow data, this could be used to estimate surface water nutrient loading. Likewise, the Long Island Regional Planning Board also collects limited nutrient data (total nitrogen) for its Land Use and Stream Assessment Program, and the South Shore Estuary Watch (SSEW) began monthly monitoring of seven tributary streams to the SSER in 1999.

Ecosystem Response Monitoring

<u>Estuarine water quality</u>

The most extensive water quality monitoring program in the SSER is conducted by the Suffolk County Department of Health Services, Bureau of Marine Resources (Suffolk County 1999). This program was started in 1977. Data are gathered at 42 stations in the estuary, biweekly from May to September and monthly thereafter. Monitoring variables for this program include temperature, salinity, dissolved oxygen, Secchi depth, a full suite of organic and inorganic nitrogen and phosphorus nutrients plus inorganic silica, chlorophyll-*a* (total and nano-plankton), *Aureococcus* abundance, and bacteriological monitoring. Twenty of the stations for this program fall within, or in close proximity to, FIIS.

Outside the immediate domain of FIIS, but within the SSER, the town of Hampstead conducts its East Bay and West Bay monthly sampling surveys at 30 stations. Monitoring variables for this program include Secchi depth, temperature, salinity, dissolved inorganic nitrogen and phosphorus, particulate organic matter, chlorophyll-*a*, dissolved oxygen, biochemical oxygen demand, and bacteriological monitoring.

Review of additional ecosystem response monitoring programs

Other ecosystem response monitoring programs include:

- *Pfiesteria* monitoring by NYC DEC, Suffolk County and the town of Hampstead. This program was started in 1999 at 27 stations in Suffolk County and Hempstead and includes temperature, salinity, nutrients, total suspended solids, and chlorophyll-*a* in its sampling suite. Sampling occurs 1-3 times starting in July.
- NYS DEC conducts aerial photographic surveys every five years for wetland delineation. These photographs generally penetrate to a depth of two meters or less, but could be used for limited mapping of *Zostera marina*. This could be checked against other eelgrass mapping efforts such as that of Jones and Shubel (1980) or NPS SAV maps generated from 1992 photography (available from the NPS office of GIS).


ATLANTIC OCEAN
GREAT
SOUTH
BAY
LONG
ISLAND

Figure A-6. National Park Service Visitor Map of Fire Island National Seashore.

Sagamore Hill National Historic Site (SAHI)

Character of Park Estuarine Resources

Sagamore Hill National Historic Site (SAHI) is a small, 34-ha cultural/historical park on Cold Spring Harbor, which is a branch of Oyster Bay on the north shore of Long Island, just twenty-five miles east of New York City (Figure A-7). The park's approximately 200m of shore frontage is largely a beach of shell hash, behind which there is a small impounded salt marsh that is flushed by a tidal creek connecting it to Cold Spring Harbor. Land use in the watershed draining directly into the tidal marsh is dominated by the park itself, and by a few large neighboring private estates. The Oyster Bay – Cold Spring Harbor complex lies in the midst of the highly urbanized and suburbanized northeast seaboard, one of the most densely populated regions in the nation. The Long Island Sound Study (LISS), a cooperative effort of federal, state and local governments, concluded that low dissolved oxygen is the most acute threat to the health of the Long Island Sound ecosystem. Friends of the Bay (FOB), a local advocacy and monitoring group, reported that approximately half of its weekly monitoring surveys of Cold Spring Harbor during the summer of 2000 revealed dissolved oxygen concentrations that did not meet the New York State minimum standard of 5.0 mg/l for Class SC water, the lowest classification suitable for primary contact recreation such as swimming (FOB 2001). The lowest dissolved oxygen level recorded in Cold Spring Harbor for 2000 was 1.24 mg/l, causing it to fail even the lowest standard for Class SD water. This is the water class designation used where no contact recreation is appropriate, and the water is suitable for fish survival only. Nevertheless, this embayment, much of which falls within a 1,295-ha National Wildlife Refuge, is considered the cleanest in western Long Island Sound, and supplies up to 90% of the annual New York State oyster harvest (FOB 2001).

Landscape Monitoring/Tracking

Land use and land cover data are available from the NOAA C-CAP Coastal Change Analysis Program. Also, national land cover data (15 land classes) is available from the Multi-Resolution Land Characteristics Consortium from 1991 and 1992 imagery.

Nutrient Stressor Monitoring

There are no NADP or AIRMoN stations for monitoring atmospheric deposition of nutrients in the immediate vicinity of SAHI. The closest NADP site is NY99 at West Point, so estimates for deposition at the park would necessarily rely on NADP data contoured from all the regional sites.

New York and Connecticut have identified Long Island Sound as "water quality limited" due to hypoxia. Provisions of the federal Clean Water Act and EPA's implementing regulations thus required that a total maximum daily load (TMDL) be established for nitrogen to Long Island Sound. As part of this process, current loading budgets were developed for Long Island Sound

(LISS 2000). National Pollutant Discharge Elimination System (NPDES) permits and compliance monitoring data are available from the New York State Department of Environmental Conservation, Division of Water, to track loading to Oyster Bay from sewage and industrial discharges. Currently there is a single municipal sewage treatment plant that discharges in the embayment, and four smaller permitted discharges.

Ecosystem Response Monitoring

Friends of the Bay, Oyster Bay, NY

FOB was formed in 1987 and started its water quality sampling program in response to cutbacks by the Suffolk and Nassau County Departments of Health. At present, FOB conducts the only routine ecosystem response monitoring in Oyster Bay and Cold Spring Harbor. Six stations (two in Cold Spring Harbor) are occupied weekly from May through October. Temperature, salinity, and dissolved oxygen are measured at 1m intervals through the water column, Secchi depth is determined, and a surface water sample is collected for bacteriological analysis. Stations are occupied within several hours of dawn in order to capture daily oxygen minima. FOB has considered building upon their program, and may in the near future add dissolved inorganic nutrients, pH, and apparent color to their suite of monitoring variables.

Review of additional monitoring programs

Other ecosystem response monitoring programs include:

- Interstate Environmental Commission (IEC). Formerly the Interstate Sanitation Commission, this organization represents NY, NJ, and CT. They monitor 67 stations (33 long term) in NY/NJ Harbor and LI Sound. Sampling frequency is bi-weekly during the summer, and monthly during the rest of the year. Variables include temperature, salinity, dissolved oxygen, chlorophyll-*a*, turbidity, total organic carbon, and a full suite of nitrogen and phosphorus nutrient species. There are no stations in Oyster Bay or Cold Spring Harbor, but there are representative stations for Long Island Sound.
- Suffolk County Department of Health used to run an extensive monitoring program that was effectively eliminated in 1998. Monitoring had included a full suite of nitrogen and phosphorus nutrient species, dissolved oxygen, chlorophyll-*a*, *Aureococcus,* Secchi depth, temperature, salinity, total suspended solids, total organic carbon, dissolved organic carbon, and bacteriological monitoring.

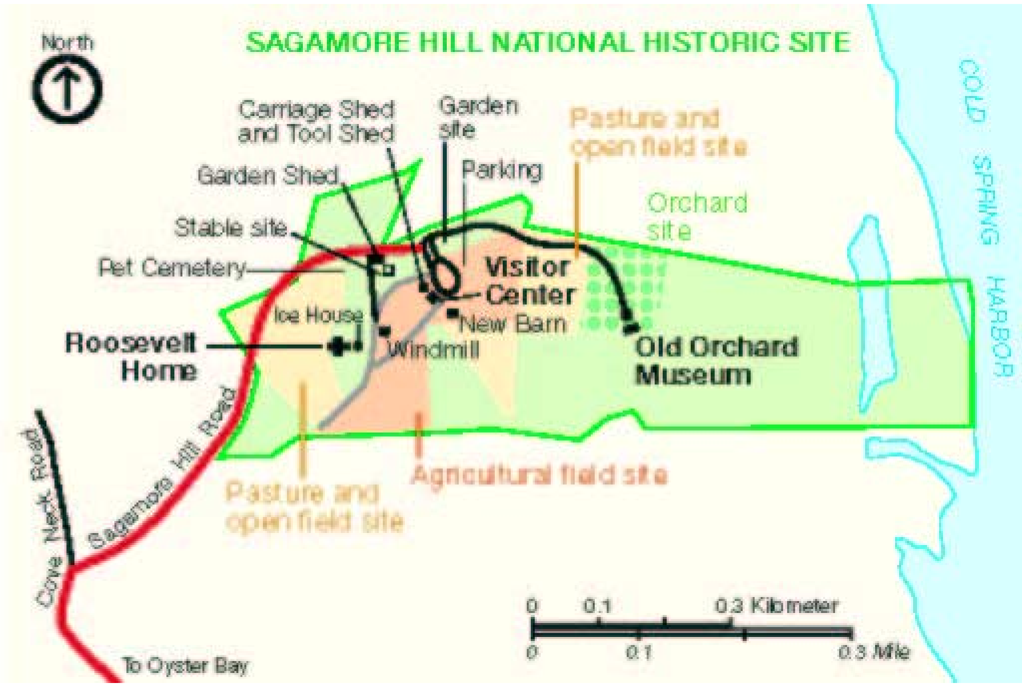


Figure A-7. National Park Service Map of Sagamore Hill National Historic Site on Cold Spring Harbor, Oyster Bay, NY.

Cape Cod National Seashore (CACO)

Character of Park Estuarine Resources

Cape Cod is a large glacial peninsula that extends 96.5 km into the Atlantic Ocean from the coast of Massachusetts. Cape Cod National Seashore (CACO) is located in Barnstable County on the outer cape (Figure A-8). It was established in 1961 and contains 18,063 ha of marine, estuarine, freshwater, and terrestrial ecosystems. Much of the estuarine habitat at CACO is associated with two large coastal lagoon systems. Pleasant Bay, 2,948 ha in area, is the largest bay contiguous to the Seashore. It is isolated from the Atlantic Ocean by a barrier beach approximately12 km in length (known as Nauset Beach in Orleans and North Beach in Chatham), which is wholly situated within the boundary of the Cape Cod National Seashore. The other large coastal lagoon, Salt Pond, is a forty-foot deep glacial kettle hole that has been breached and filled with seawater.

Barnstable County is among the fastest growing counties in the northeastern U.S. During the period from 1980 to 1990, the population grew roughly five times faster than the state as a whole, then again almost four times faster during the period from 1990 to 2000 (US census data). Projections for the period from 2000 to 2010 anticipate a population increase of another 25% while the state grows by approximately 5.5% (MISER 1999). In 1990, in the wake of the unprecedented growth of the 1980s, the Cape Cod Commission was created by an act of the Massachusetts General Court and confirmed by Barnstable County voters. It was established as a regional planning and regulatory agency to prepare and implement a regional land use policy.

The National Park Service selected CACO to serve as a prototype monitoring park for the Atlantic Coastal and Barrier Island network. The USGS-Biological Resources Division, in collaboration with the NPS, has been responsible for designing and testing the prototype (Roman and Barrett 1999). The protocol for estuarine nutrient enrichment has been developed and evaluated under the direction of Dr. Charles Roman of the NPS (formerly with the USGS) and Dr. Barbara Nowiki of the University of Rhode Island. The final product in currently in draft.

Landscape Monitoring

As with all the network parks, land use and land cover data are available from the NOAA C-CAP Coastal Change Analysis Program. Also, national land cover data (15 land classes) are available from the Multi-Resolution Land Characteristics Consortium from 1991 and 1992 imagery. In addition, changing land use patterns will be monitored in terms of (a) conversion of summer to all year round status, (b) municipal water use records, and (c) land use/zoning surveys. The Cape Cod Commission assembles most of these data sets.

Nutrient Stressor Monitoring

A National Atmospheric Deposition Program (NADP) station (MA01) is located within the boundary of CACO at the NPS North Atlantic Coastal Lab and has been in operation since 1981. This allows for monitoring of wet deposition of nutrients in CACO. Because of the sandy soils and a burgeoning number of individual septic disposal systems, ground water is the primary mechanism of excess nutrient delivery to the salt ponds and coastal lagoons of CACO. Nutrient loading has therefore been included in development of the prototype monitoring program. In the experimental phase, ground water flux and nitrate concentration were monitored seasonally at ten sites throughout the seashore. Currently, within-site variability, between-site variability, and seasonal variability are being evaluated to determine if this is an appropriate method for measuring groundwater N loading in a long-term monitoring framework.

Ecosystem Response Monitoring

As part of prototype development, CACO established numerous water quality monitoring stations throughout the Seashore, and on a monthly basis sampled inorganic nutrients, chlorophyll-*a*, temperature, and salinity. Samples were gathered at three depths (surface, middle, bottom), and on 3 simultaneous days to account for day-to-day variability. These data are being analyzed to establish variability within sites, with depths, and with seasons. The monitoring protocol will also likely include some degree of continuous dissolved oxygen monitoring in select estuarine basins with long flushing times and where dissolved oxygen problems are anticipated.

Macroalgae species composition and biomass were evaluated during the experimental phase of protocol development. Macroalgae was sampled monthly from April to November and once in February from sites along a disturbance gradient, from developed to undeveloped portions of CACO estuaries. These data are being analyzed to identify trends in species composition or biomass that occur with estuarine development, and to identify any species that could be indicators of nutrient enriched conditions. The data will also be useful to pinpoint thresholds of nutrient loading that may cause shifts in algal species composition or abundance.

Habitat maps, from aerial photos, will be completed on about 5-yr intervals to map the extent of eelgrass, macroalgal beds, and marsh habitat. Aboveground eelgrass biomass may also be monitored.

Figure A-8. National Park Service Visitor Map of Cape Cod National Seashore.

Boston Harbor Islands – A National Park Area (BOHA)

Character of Park Estuarine Resources

Boston Harbor Islands National Park Area (BOHA) is a unique unit of the National Park Service. NPS does not independently own and manage BOHA; rather the enabling legislation of 1996 established NPS as one of 13 members of a management partnership. Additional members of the Boston Harbor Islands Partnership include representatives from four agencies/authorities from the Commonwealth of Massachusetts, two municipal bodies from the City of Boston, three non-governmental organizations, one other federal bureau, and two representatives from the Boston Harbor Islands Advisory Council.

BOHA consists of over 405 ha of coastal woodlands, dunes, freshwater wetlands, estuarine and marine wetlands, and sandy and rocky beaches scattered over 32 glacial drumlin islands and former islands (now peninsulas) within the 130 square km area of Boston Harbor (Figure A-9). For descriptive and management purposes, the islands are grouped by BOHA into four clusters: the inner harbor islands of Dorchester Bay, closest to Boston; the Quincy Bay islands; the Hingham Bay Islands; and the outer bay islands or Brewsters. Three major rivers provide fresh water to create estuarine conditions in Boston Harbor. These are the Charles, the Mystic and the Neponset Rivers.

Although the waters of Boston Harbor are not included within the national park area boundary, water quality in the harbor plays a direct and significant role in the status and health of natural resources within the park, and also upon visitor use and enjoyment. Boston Harbor has a semidiurnal tide with a mean amplitude of 3.15 m. Consequently, large areas of intertidal lands that are included within BOHA are directly affected by harbor water quality. Uplands are also strongly tied to the health of the surrounding harbor. Water quality in Boston Harbor has improved markedly since the late 1980s. Before this time, direct discharges of sewage and industrial effluent caused it to be one considered the most polluted harbor in the US (Flora 2002). For over a century, the harbor received discharges of wastewater from the City of Boston and surrounding communities. Over the past 50 years, the bulk of this discharge was contributed by two wastewater treatment facilities, which until relatively recently, offered only primary sewage treatment. In response to law suits filed and won under the federal Clean Water Act, a massive effort to improve wastewater treatment was launched, and in 1985 the Massachusetts Water Resources Authority (MWRA) was established. In 1998, sewage from the Nut Island plant was diverted to an upgraded wastewater treatment facility at Deer Island. Then in 2000, the effluent from this modernized facility was diverted away from its discharge in the harbor through a 24ft diameter tunnel to discharge diffusers 9.5 miles east of Deer Island in Massachusetts Bay. The MWRA continues to monitor the effect of these improvements upon the ecosystems both within the harbor itself, and in Massachusetts Bay. It also continues to work on the problem of sewage and nutrient loading to Boston Harbor via combined sewer overflows and storm water discharges (MWRA 1997).

Landscape Monitoring

Land use and land cover data are available from the NOAA C-CAP Coastal Change Analysis Program. Also, national land cover data (15 land classes) are available from the Multi-Resolution Land Characteristics Consortium from 1991 and 1992 imagery.

Nutrient Stressor Monitoring

Atmospheric deposition of nitrogen is monitored at the NADP station MA13, which is located at the University of Massachusetts Suburban Experiment Station in Lexington. This station has been in operation since 1982. National Pollutant Discharge Elimination System (NPDES) permits and compliance-monitoring data are available to track nutrient loading from point-source discharges. The MWRA is the single largest permitted authority and now discharges the bulk of its effluent into Massachusetts Bay. Monthly monitoring reports on volume and constituents are prepared for each permitted discharge. NPDES permits in Massachusetts are federally implemented by the US EPA.

Ecosystem Response Monitoring

<u>Massachusetts Water Resources Authority</u>

Water Quality

The most comprehensive monitoring program for Boston Harbor and Massachusetts Bay is conducted by the MWRA in support of its activities to track ecosystem responses to changing sewage discharge patterns. MWRA initiated its harbor-wide Boston Harbor Water Quality Monitoring Project (BHWQMP) in 1993, four years before instituting secondary treatment at Deer Island, five years before the intra-island transfer of effluent to Deer Island from the decommissioned Nut Island STP, and seven years before cessation of discharges into Boston Harbor and diversion of effluent to Massachusetts Bay via the new outfall and diffusers. Nine stations, not including stations specifically targeting outfalls, are monitored as part of the BHWQMP (Taylor 2001). Eight of these are located in the vicinity of the Boston Harbor Islands (Flora 2002). Stations are occupied throughout the year, with the following parameters measured at both the surface and near the bottom: temperature, salinity, turbidity, pH, dissolved oxygen, photosynthetically available radiation, Secchi depth, transmissivity, total suspended solids, chlorophyll-*a* and pheopigments, phytoplankton species composition, total organic carbon, total dissolved nitrogen and phosphorus, dissolved inorganic phosphorus and nitrogen species, particulate nitrogen, particulate organic carbon, and bacteriological monitoring. In addition to these receiving-water stations, MWRA also monitors three former outfall stations (surface only: temperature, salinity, dissolved oxygen, turbidity, transmissivity, Secchi depth, photosynthetically available radiation, dissolved inorganic nutrient species, and bacteriological monitoring), and two stations as part of their CSO monitoring program (surface and bottom: temperature, salinity, dissolved oxygen, turbidity, pH, Secchi depth, transmissivity, and fecal coliform), and . Combined, this constitutes 13 stations in the BOHA vicinity with relevant water quality monitoring activities (Rex and Taylor 2000).

Benthic Monitoring
Since 1991, when in-harbor dumping of sewage sludge was discontinued, benthic infaunal community structure and species abundance have been monitored semi-annually by the MWRA at eight stations within Boston Harbor. In addition to species parameters, total organic carbon and sediment grain size are also measured. In addition, sediment profile imagery was added in 1999 at a much higher spatial resolution (60 stations, Kropp et al. 2000).

Review of additional monitoring programs

Other ecosystem response monitoring programs include:

- The Mass. Department of Environmental Protection (DEP) Wetlands Conservancy Program (WCP) developed and completed a project to map the seagrass resources of the entire Massachusetts coastline. This mapping effort was conducted from 1994 through 1997 with assistance from the National Oceanic and Atmospheric Agency Coastal Change Analysis Program (C-CAP) and the NOAA Coastal Services Center. DEP would like to renew these maps on a five-year rotation pending availability of resources.

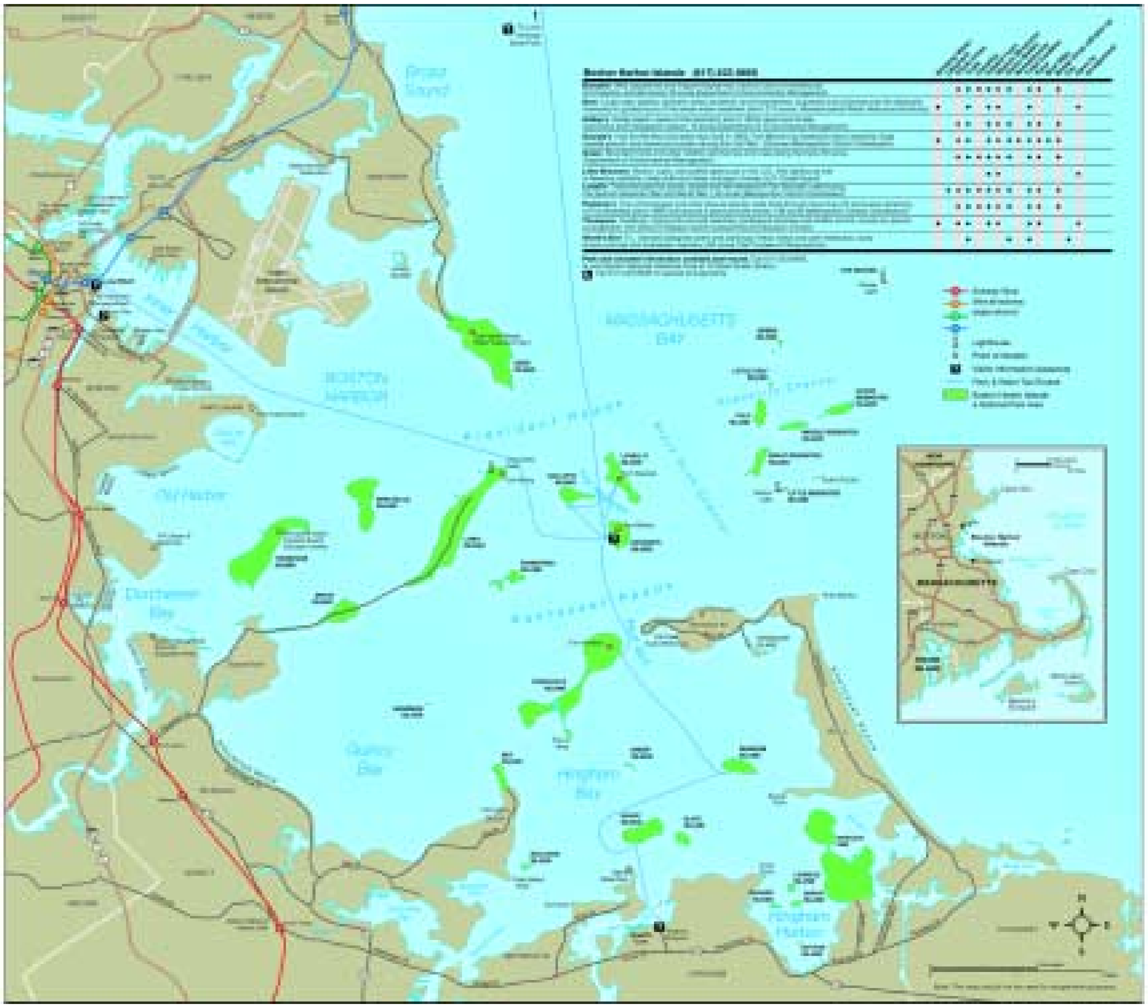


Figure A-9. National Park Service Visitor Map of Boston Harbor Islands – a National Park Area.

Acadia National Park (ACAD)

Character of Park Estuarine Resources

Acadia National Park (ACAD) occupies the highest rocky headlands on the Atlantic coast of the US and encompasses approximately 16,500 hectares in three primary units on Mount Desert Island, Isle au Haut, and the Schoodic Peninsula (Kahl et al. 2000, Figure A-10). Smaller outlying islands are also part of the park, and ACAD is actively engaged in conserving additional land through the acquisition of conservation easements. National Wetland Inventory classification for ACAD identifies 118 hectares of marine and 149 hectares of estuarine wetland habitat falling inside park boundaries (Kahl et al. 2000). Significant estuarine resources also lie outside and adjacent to the park. Three small estuaries on Mount Desert Island lie within or directly adjacent to park lands. Somes Sound is an 8-km long and 1 km wide fjord-type estuary. Bass Harbor Marsh and Northeast Creek are both expansive tidal creek estuarine systems characterized by salt marsh, tidal fresh marsh, and SAV beds dominated by *Ruppia maritima.* Bass Harbor Marsh consists of over 349 ha of estuarine and freshwater wetland and open water (Kinney and Roman 1998), and the Northeast Creek system (also know as Fresh Meadow) consists of over 200 ha (Nielsen 2002). Smaller coves and embayments with estuarine resources are found elsewhere on Mount Desert Island as well as within the Schoodic and Isle au Haut units.

As is characteristic of all fjords, Somes Sound has a shallow sill at its mouth with the potential of limiting the exchange of deep water. Here, however, the estuary does not stratify so severely that bottom waters become anoxic (Doering and Roman 1994). Nutrient loadings to the sound are low, and *in situ* concentrations of nutrients, chlorophyll-*a* and dissolved oxygen all indicate a relatively pristine system (Doering and Roman 1994). By contrast, the estuary at Bass Harbor Marsh has begun to experience eutrophic conditions from increased nutrient loading (Doering et al. 1995). Northeast Creek is still a relatively pristine system with regard to nitrogen load (Nielsen 2002), but dramatic growth of residential development in the watershed has prompted a current USGS research project to better understand its susceptibility to eutrophication.

Landscape Monitoring

Land use and land cover data are available from the NOAA C-CAP Coastal Change Analysis Program and the Multi-Resolution Land Characteristics Consortium. For the latter, mapping is available from 1991 and 1992 imagery, and land is classified into 15 classes. Incomplete information on housing density and individual septic disposal systems is available from local municipal governments.

Nutrient Stressor Monitoring

A National Atmospheric Deposition Program (NADP) station (ME98) is located within the boundary of ACAD, and has been in operation since the year 1981. There is no ongoing monitoring of surface water flow or nutrient loading into the major three estuaries of ACAD, but loading studies have been conduced at each of them within the past decade (Doering et al. 1995, Doering and Roman 1994, Nielsen 2002).

National Pollutant Discharge Elimination System (NPDES) permits and compliance monitoring data are available from the Maine State Department of Environmental Protection and U.S. Environmental Protection Agency Region 1 Office. In Maine, however, nutrients are not themselves identified as pollutants in NPDES permits for wastewater treatment plants. Consequently, they are not required monitoring variables, and any estimates of point source loading of nutrients to ACAD would have to be estimated from proxy variables such as effluent volume and BOD. Seven licensed wastewater discharges are currently on record adjacent to ACAD (Kahl et al. 2000).

Ecosystem Response Monitoring

There are essentially no monitoring programs in existence for tracking changes to habitats, living resources, or water quality in estuaries at ACAD. One exception is the ongoing macroalgal community monitoring conducted for scholarly purposes by A. Mathieson at the University of New Hampshire. Dr. Mathieson tracks community composition and zonation patterns at numerous stations within and adjacent to ACAD. He has also compared modern assemblages to historic ones reconstructed from numerous studies dating back to the late 1800s (Mathieson et al. 1998). His monitoring does not, however, examine drift macroalgae that are commonly associated with eutrophication responses in shallow soft-bottom habitats such as Bass Harbor Marsh and Northeast Creek.

Also available for historical monitoring comparisons are the invertebrate inventories conducted by William Procter in the early 1900s. In over 27 seasons of fieldwork, Procter inventoried the insects and other invertebrates of Mount Desert Island, including the marine invertebrates (Procter 1933).

The State of Maine Department of Marine Resources has completed distribution maps of eelgrass with intentions of keeping them up to date, but no programmatic mapping goals have been set with respect to the frequency of remapping (S. Barker personal communication). Additionally, this mapping effort does not include more brackish waters and the SAV communities of *Ruppia maritima* they support.

Figure A-10. National Park Service visitor map of Acadia National Park (A) with units at Isle au Haut (B), Schoodic Point (C), and Mount Desert Island (D).

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